Brain Electric Idiosyncrasies and Commonalities of Meditation States.

Thesis (cumulative thesis)
Presented to the Faculty of Arts and Social Sciences
of the University of Zurich
for the Degree of Doctor of Philosophy

by Pascal L. Faber

Accepted in the Autumn Term 2015
on the Recommendation of the Doctoral Committee:
Prof. Dr. rer. nat. Lutz Jäncke (main advisor)
Prof. Dr. Reto Huber

Zurich, 2015

To Lisa, Nikki and Eric,
my wife and children

Table of Contents

Summary

The brain-electric idiosyncrasies and commonalities of meditation practices from different meditation traditions are investigated using electroencephalography (EEG). Three studies are reported. Study I directly compares two meditations from the Qigong tradition, ‘Qigong’ (using breath synchronized slow arm movements) and ‘Thinking of Nothing’ (to think of nothing, suppressing intruding thoughts) and compares them to no-task resting. Study II compares the classical practice from the Zen tradition, ‘Zazen’ (the non-judgemental and non-clinging observation of ongoing experience on a moment-to-moment basis) to no-task resting. Study III investigates 5 groups of meditators from different traditions (Qigong, Sahaja Yoga, Ananda Marga Yoga, Tibetan Buddhism and Zen), each group performing the meditation practice considered to lead to the deepest meditation state which was then compared to no-task resting. Study I and study II describe in detail the idiosyncratic brain electric activation patterns underlying the three practices of ‘Qigong’, ‘Thinking of Nothing’ and ‘Zazen’. Study III reveals a remarkable commonality between deep meditation states generated by practices from 5 different traditions: the reduction of functional connectivity in all EEG frequency bands. Study III also shows that different brain electric mechanisms lead into meditation than out of meditation. Future studies need to differentiate between practice and state.

Zusammenfassung

Die hirnelektrischen Eigenheiten und Gemeinsamkeiten von Meditationspraktiken aus verschiedenen Traditionen werden mit Hilfe des Elektroenzephalogramms (EEG) in drei Studien untersucht. Studie I vergleicht zwei Meditationspraktiken aus der Qigong Tradition, 'Qigong' (langsame mit dem Atem synchronisierte Armbewegungen) und 'Thinking of Nothing' (an nichts denken, auftretende Gedanken werden unterdrückt) miteinander und auch mit aufgabenfreier Ruhe. Studie II vergleicht die klassische Praktik der Zen Tradition, 'Zazen' (dem bewertungsfreiem und nicht haftendem Beobachten der Erfahrungen im Moment) mit aufgabenfreier Ruhe. Studie III untersucht fünf Gruppen von Meditierern aus den Traditionen Qigong, Sahaja Yoga, Ananda Marga Yoga, Tibetischer Buddhismus und Zen. In jeder Gruppe wird die Praktik, welche erfahrungsgemäss zu dem tiefsten Meditationszustand führt mit aufgabenfreier Ruhe verglichen. Die Studien I und II beschreiben im Detail die hirnelektrischen Aktivierungsmuster der Praktiken 'Qigong', 'Thinking of Nothing' und 'Zazen'. Studie III deckt eine bemerkenswerte Gemeinsamkeit auf zwischen den tiefen Zuständen, welche durch Praktiken aus 5 verschiedenen Traditionen hervorgerufen wurden: die Verminderung der funktionellen Konnektivität in allen Frequenzbändern. Studie III zeigt ebenfalls, dass unterschiedliche hirnelektrischen Mechanismen in die Meditation hineinführen als daraus heraus. Zukünftige Studien müssen unterscheiden zwischen der Praktik und dem Zustand.

1. Introduction

Meditation is allowing what is.

by Victor Davich

There are many meditation traditions, e.g. Yoga, Zen, Qigong. Across meditation traditions and their many subdivisions, a lot of different meditation practices exist. Despite the many differences between practices (see section 1.1.1.), most meditation practices share similar goals (see section 1.3.). Also the regular practice of meditation has many benefits (see end of section 1.1.1.). Meditation has become very popular in the last forty years in the western world and is today an important topic in cognitive neuroscience research. The many different practices and their similar goals lead to the two questions that are at the heart of this thesis: What are the differences between and the idiosyncrasies of the different practices? And what are the commonalities between them? The framework and tool for answering these questions will be the brain electric activity. The electroencephalography (EEG) since its invention by Hans Berger in 1920 (Berger 1929) has proven its usefulness in describing and understanding the neural underpinnings of mental processes in different normal and altered states of consciousness (Jäncke 2005, Lehmann 2013). The present thesis centers on the brain electric idiosyncrasies and commonalities as measured and described with EEG of different meditation practices. Meditation will be looked at primarily from a neuroscientific point of view. Literature concerning meditation in the context of religion only will be largely ignored.

In the subsections of this introduction, I shall elaborate on what meditation is and what it is not. I'll explain in detail the rationale behind the search for idiosyncrasies and commonalities between different meditation practices. Then in section 1.4. I'll introduce the EEG analysis methods of choice used in the studies presented in chapter 2, which are intracortical source modeling and intracortical lagged connectivity. I'll also briefly sketch EEG microstate analysis, a method that seems promising for future studies on meditation. The main part of this thesis is chapter 2, which contains 3 studies searching for answers to the 2 questions of this thesis: What are the brain electric idiosyncrasies of different meditation practices? And what are the brain electric commonalities of deep meditation states reached through different meditation practices? The first two studies concern the idiosyncrasies of two practices from the Qigong tradition ('Thinking of Nothing' and 'Qigong') and the main practice of the Zen tradition ('Zazen'). The two Qigong practices will be compared against each other and all three practices will be compared to no-task resting. The third study investigates the commonalities of meditation practices from the five different traditions of Tibetan Buddhism, QiGong, Sahaja Yoga, Ananda Marga Yoga and Zen Buddhism. In the third and last chapter I shall then discuss more generally the findings presented in chapter 2.

First, let's have a closer look at what meditation actually is.

1.1. What is meditation?

> Meditation is the dissolution of thoughts in
> Eternal awareness or Pure consciousness
> without objectification,
> knowing without thinking,
> merging finitude in infinity.
>
> by Swami Sivananda

The practice of meditation leads to a state of mind that belongs to the family of altered states of consciousness (Tart 1969, Dittrich 1985, Vaitl, Birbaumer et al. 2013). One way of classifying altered states of consciousness is by their origin. They can be spontaneous, induced or pathological (Vaitl, Birbaumer et al. 2013). Meditation states belong to the category of induced altered states of consciousness as they typically are willfully self-induced. Most meditation traditions recommend an isolated, quiet and comfortable setting for the practice of meditation (Shear 2006). In one typical meditation session, the meditator sits down and exercises the detached observation of ongoing experience. The intention is to not analyze, not judge and not expect anything (Maupin 1969, Cardoso, de Souza et al. 2004). Another typical meditation practice is to sit relaxed and focus the attention on a special object or sensation and let interfering thoughts pass by and refocus on the object of attention. The attention can be focused on the sensations at the nostrils when breathing in and out, it can be focused on counting one's breathing, on internally repeating a mantra, on visualizing an image, or on externally watching the flickering flame of a candle. There are many different meditation practices and in section 1.1.1. I shall give examples and cover these in more depth.

More generally and seen through a more scientific lens, the term meditation encompasses a family of practices that regulate attention, awareness and emotion (Shapiro and Walsh 2003, Raffone and Srinivasan 2010). Through training attentional and emotional control, the meditation practices usually aim at psychological and spiritual wellbeing and maturity (Shapiro and Walsh 2003), heightened spiritual awareness or somatic calm (Encyclopaedia Britannica 2015) and existential insight (Lifshitz, Campbell et al. 2012). According to Sperdutti et al. (2012), the general common goal of all meditation practices is to induce relaxation, to regulate attention and to develop an attitude of detachment from one's own thoughts. Jaseja (2009) proposes a definition of meditation founded in the process and outcome of meditation. Meditation should be regarded as ‘‘a complex neural practice that induces changes in neurophysiology and neurochemistry of brain resulting in altered neurocognition and behavior in the practitioner" (Jaseja 2009, p. 483). In the present thesis the main focus lies precisely on finding out more about the neurophysiological changes during the practice of meditation.

1.1.1. Meditation practices

HOW TO MEDITATE

— lights out —

fall, hands a-clasped, into instantaneous
ecstasy like a shot of heroin or morphine,
the gland inside of my brain discharging
the good glad fluid (Holy Fluid) as
I hap-down and hold all my body parts
down to a deadstop trance — Healing
all my sicknesses — erasing all — not
even the shred of a "I-hope-you" or a
Loony Balloon left in it, but the mind
blank, serene, thoughtless. When a thought
comes a-springing from afar with its held-
forth figure of image, you spoof it out,
you spuff it out, you fake it, and
it fades, and thought never comes — and
with joy you realize for the first time
"Thinking's just like not thinking —
So I don't have to think
any
more"

by Jack Kerouac
(The Portable Jack Kerouac, Portable Library)

The many different meditation practices can have several aspects. Technical aspects for example are the involvement of body and breath, awareness and non-semantic objects. Many meditation practices also have aspects that are more thematic, scriptural and devotional in nature (Eifring 2013), like prayer and contemplation meditations. Typically these meditations have a more religious background and employ meditation techniques such as meaning-based recitation and visualization. Examples of practices including one or several of these aspects will follow shortly.

In many meditation traditions, calming the body and the mind is a prerequisite to deeper meditation states. Practices that involve focusing one's attention on a single object (e.g. breathing) help calm the mind and open the way to mindfulness or open awareness practices (Dunn, Hartigan et al. 1999, Lutz, Slagter et al. 2008, Malinowski 2013). Non-attachment and the renouncing of the subject-object relationship are sought (Fischer 1976). Increasingly deep concentration is needed to advance to more self-analytical and insightful meditation practices. In order to not be misguided at this stage of progression, many traditions demand the previous study of pertinent texts (scriptures) to attain the necessary moral basis for fruitful self-analysis. This often is accompanied by tuning the body (through nutrition and exercise) and general behavior in everyday life according to high moral standards. Depending on the tradition, the ultimate goal is Self-realization, the unification with God or some universal force, or self-dissolution, emptiness or transcendence. Typically there are many different practices that cover different parts of this process. It is not the goal of this section to give a complete overview of meditation practices. Rather, this section should give an idea about the diversity of the different approaches to meditation. I shall exemplify this diversity by describing some typical practices taken from different meditation traditions.

A first example is Zazen, which is a practice of the Zen Buddhism tradition. Zazen consists of 'just sitting', or as Dogen put it: ''sitting fixedly, think of not thinking. How do you think of not thinking? Nonthinking. This is the art of Zazen'' (Zazen gi: Dogen 1243/2011). This basically means that the practitioner aims for a detached mindful perception of the ongoing moment-to-moment experience (Austin 2013). Typically the practitioner sits on a meditation cushion (zafu) in a full or part Lotus position with his/her hands held together in front of the navel. Posture and breathing are of high importance, as they should be such as to allow effortless bodily and mental calmness and thus reduce the amount of intruding thoughts (Harada-Roshi 2006). Contrary to some other meditation practices that favour absorption and the withdrawal from the environment, Zazen through keeping the eyes slightly open and through keeping a certain posture specifically promotes some degree of active tension and thus avoids falling into a state of dreaminess (Pagnoni, Cekic et al. 2008).

Another example comes from the Qigong tradition and superficially seems similar to Zazen: the practice of 'Thinking of Nothing'. This Qigong practice aims at not thinking and not feeling anything, to dissolve into emptiness (Faber, Lehmann et al. 2012). The difference to Zazen is that thoughts are actively suppressed, while during Zazen practitioners are mindful of their thoughts with a non-judgmental and detached stance, just noticing them and letting them go. Both practices though lead to a reduction of intruding thoughts.

A very different practice comes from the Transcendental Meditation (TM) tradition. The basic practice of TM consists at the beginning of a meditation session of internally attending to a personal, though meaningless two-syllable mantra, thus turning the attention away from external and physiological events to more silent states of mind, a process called transcending (Travis and Arenander 2006). The practitioner sits comfortably with eyes closed during meditation, for 20 minutes twice a day. Unlike other practices that use mantras, the basic TM practice does not consider intruding thoughts as off-task, but as part of the meditation process.

A similar, technically 'simple' meditation practice using a mantra is found in Christianity: the centering prayer. While sitting relaxed and quietly with eyes closed, the practitioner focuses on a chosen sacred word that symbolizes the practitioner's intention to consent to God's presence and action within him-/herself. When the practitioner becomes aware of intruding thoughts, he/she is to gently return to the sacred word (Pennington 2006). One major difference to TM is that the chosen sacred word is loaded with meaning. Also intruding thoughts are considered off-task. And clearly, the centering prayer has strong devotional aspects while TM is a purely technical practice, allowing the mind to settle in silence without giving it any direction.

Concentrating on certain feelings also is a common meditation practice. Especially feelings of loving-kindness are incorporated in many practices. Loving-kindness or compassion meditations involve the unconditional readiness and availability to help living beings (Lutz, Greischar et al. 2004) and the equanimity towards all beings and appreciation and affection for others (Desbordes, Negi et al. 2012). The practitioner cultivates such feelings while focusing on certain persons or groups of beings or on all sentient beings. The feelings of love and compassion grow and eventually fill the entire mind, leaving no room for discursive thoughts (Lee, Leung et al. 2012).

Many meditation practices involve body postures (e.g. Lotus position) or even body movements. An example is a practice from the Chinese Taoist Qigong tradition, during which the practitioner stands and performs breath-synchronized slow arm movements while thinking of nothing and transcending (Faber, Lehmann et al. 2012). Typical for many Qigong practices is the focus on working in some way or other on circulating energy through the body, this energy being the universal life-force 'qi' (Liang and Wu 2006). This practice differs from the already mentioned pratices in that part of the attention is needed for monitoring the slow arm movements and the flow of 'qi'.

As with the sensation of the flow of 'qi', many practices use different sensations in the body or parts of the body as focus for attention. A common practice in many meditation traditions is to focus on some aspect or other of breathing. Breath counting is a common practice as is focusing the attention on the sensations at the nostrils when inhaling and exhaling, or the sensations in the lower abdomen (Tanden) during breathing (Yu, Fumoto et al. 2011). As we will see later in section 1.3.2., one can make a distinction between meditation practices that have a single focus of attention and those that do not have a single focus of attention. Focusing on one's breathing is an example of the former. Zazen is an example of the latter as it allows all experiences to come to attention, albeit without getting attached to them.

Some practices consist of a series of different techniques. A good example stems from the Diamond Way of Tibetan Buddhism. The practice consists of visualizing Buddha in front and on top of oneself, of internally reciting a 100-syllables mantra and of the dissolution and the reconstitution of the self (Lehmann, Faber et al. 2001). Different techniques are used during the progression through the meditation: visualization, internal verbalization, dissolution into nothingness and finally reconstitution of ego/self-boundaries. Noteworthy here is that this practice has a mixture of more technical and more meaning-endowed aspects. To the latter belongs the visualization of Buddha as a way to endow oneself with the properties of Buddha, thus guiding the practitioner in his/her moral, behavioral and spiritual aspirations. Another meditation practice that combines several different techniques comes from the Kabbalah, the Jewish esoteric and mystic tradition. During meditation the practitioner strives to move up through the tree of life (cf. Figure 1) to finally merge with an undifferentiated divine unity. This complex meditation practice uses visualizations of the 10 divine emanations (sefirot, cf. figure 1), of lights and divine names combined with enunciations of words of prayer and is accompanied by a sense of ascending to the infinite (Brill 2013). Contemplation of the meaning of the sefirot and the paths that connect them leads to a purification that ultimately enables the practitioner to behold and merge with the divine and drawing down divine energy. Subjectively, this leads to self-effacement, transcendence and feelings of nothingness or oneness (Brill 2013). Complex meditation practices like this one or the previous Tibetan Buddhist practice can also be found in traditions like Daoism or Hindu Tantric yoga.

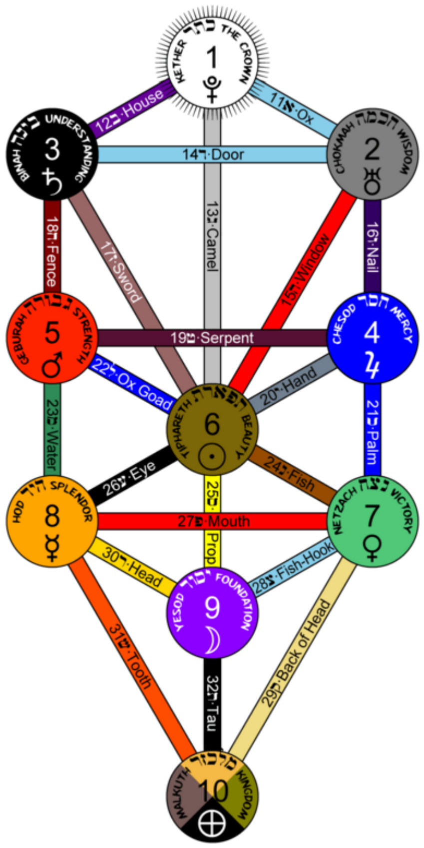

Figure 1: The Tree of Life (http://commons.wikimedia.org/wiki/File:Tree-of-Life_Queens-Colour.png#file), consisting of the 10 sefirot (circles) that are interconnected by 22 pathways. Sefirot and pathways have many layers of correspondences.

These are only a few examples of very different simple and more complex meditation practices from different traditions. They suffice to illustrate that the emphasis of each practice can be on very different aspects. The emphasis can be on reducing the focus of attention or enlarging it, it can be on imbueing oneself with certain moral standards, on non-judgementally observing internal mentations and emotions or on quieting the mind through meaningful or meaningless verbalizations.

The practice of meditation is usually willful and self-induced and therefore it must yield some immediate benefits or the promise of long-term benefits for the practitioners to keep practicing. Indeed there is a long list of proclaimed benefits, including increased subjective well-being, reduced emotional reactivity and improved behavioral regulation. The list of psychological benefits includes increased life satisfaction, conscientiousness, self esteem, empathy and sense of autonomy; also, increased mindfulness, an effect of many meditation practices, correlates negatively for example with depression, neuroticism, absent-mindedness, rumination and social anxiety (for a review, see Keng, Smoski et al. 2011). Considering the positive effects of meditation practice, it becomes a worthwhile effort to study the brain functional idiosyncrasies of each meditation practice to understand which processes promote the different benefits.

1.1.2. Meditation states: demarcations

In the past, there has been some discussion about whether meditation might be just relaxation or even sleep, or possibly a hypnotic trance. This section shortly reviews a few early findings that differentiate meditation from relaxation, sleep and hypnosis.

Even though many meditation states are accompanied by deep physical and/or mental relaxation, they are different from pure relaxation states. Differences in EEG were reported early on for Zazen and yoga compared to relaxation induced by autogenic training (Etevenon, Henrotte et al. 1973). Both Zazen and yoga revealed higher amplitude alpha EEG compared to relaxation, yoga in addition showed higher beta amplitude occipitally. Davidson and Goleman (1977) reviewed findings on meditation and hypnotic states and concluded that concentrative meditation shares with relaxation an autonomic quiescence and that meditation in addition to relaxation also enhances some attentional skills. EEG frequency band analyses comparing concentration and mindfulness meditation with relaxation revealed many differences between meditation and relaxation (Dunn, Hartigan et al. 1999). Relaxation showed more delta and theta activity than both concentration and mindfulness meditation. Both meditation practices showed more posterior alpha activity than relaxation. And also beta-1 activity increased during meditation. The authors conclude that concentration and mindfulness meditation are unique forms of consciousness and not only degrees of a state of relaxation. Fell et al. (2010) later on make the point that beginners as compared to expert meditators have some neurophysiological commonalities with relaxation states, i.e. increases in theta and alpha activity, whereas expert meditators enter a meditation state more clearly different from relaxation states, i.e. in addition showing increased gamma activity. They argue that meditation states are more active states and involve cognitive restructuring and learning. The effects of meditation and relaxation also differ. In a more recent study, after a one-month intervention by either an integrative body-mind training (IBMT, a form of meditation that seeks a balanced state of body and mind) or a relaxation training, the IBMT group showed a significant increase in the network efficiency and connectivity of the anterior cingulate cortex, whereas the relaxation group did not (Xue, Tang et al. 2011).

While beginning practitioners might be in danger of falling asleep during meditation, it is clear that when the awareness is successfully kept on task, then the meditation state differs from drowsiness or sleep. Some early reports though found periods of sleep stages 1 up to 4 during TM meditation (e.g. Younger, Adriance et al. 1975, Pagano, Rose et al. 1976). When West (1980) reviewed the early findings in this regard, he concluded that meditation is different from drowsiness and sleep and might produce the ability to hold a hypnagogic state without drifting into sleep. Partly supporting findings were reported from another TM study that compared EEG frequency spectra between TM, eyes-closed rest, drowsiness, sleep onset and sleep (Stigsby, Rodenberg et al. 1981). The authors describe increases in theta and delta and decreases in alpha activity from wakefulness to sleep. TM showed a spectrum between wakefulness and drowsiness and the practitioners held this spectrum during the whole TM session. Lou et al. (1999) report that the EEG of the 9 yoga practitioners they studied during relaxation meditation (Yoga Nidra) was very different from sleep stage 1 as their alpha band activity was identical to the resting state activity.

It has been argued that meditation and hypnosis share similarities. Some neurophysiological commonalities between concentrative meditation and hypnosis have been described, mainly an increase in frontal theta activity (Holroyd 2003). Mindfulness meditation on the other hand has been clearly differentiated from hypnosis. Semmens-Wheeler and Dienes (2012) in their review make a convincing case of showing that meditation is very different from hypnosis and conclude that while hypnosis is self-deception with regard to ones intentions, meditation on the contrary, especially mindfulness meditation, is to see plainly what is there. One important point in their argumentation is related to findings concerning the dorsolateral prefrontal cortex (DLPFC), which shows increased activity during meditation and decreased activity during hypnosis.

In conclusion, meditation states are altered states of consciousness in their own right, different from relaxation, sleep and hypnosis.

1.3. Questions

Among the different meditation traditions we find a multitude of meditation practices as briefly exemplified in the previous section 1.1.1. Interestingly the proclaimed goal of these practices across traditions seems similar if not the same (Schwartz and Clark 2006): the cultivation of a certain state of mind. Thus we have many practices and one common goal. Two main sets of questions arise from this: First, what differentiates the meditation practices? What are the brain electric specialties or idiosyncrasies of each practice? Second, assuming a similar/same goal for the different practices, are there brain electric commonalities among the deeper states reached by these practices? These two questions frame the collection of studies that form the main part (chapter 2) of this thesis. The following two paragraphs delve more deeply into the ramifications of these two questions and briefly review the existing literature.

1.3.1. Idiosyncrasies

In view of the many reported benefits of regular meditation practice (Keng, Smoski et al. 2011), it seems appropriate to learn more about the brain mechanisms underlying the different practices. Knowing more about the neural processes involved might help to understand the formation of these benefits. Also, attentional, emotional and appraisal processes are of general interest in cognitive and affective neuroscience. Meditation as a practice specifically targeting the modulation of the attentional and appraisal systems of the brain thus becomes an especially promising target for studying the underlying brain electric mechanisms. Why are there so many different meditation practices? Does each subserve a different function on the road to enlightenment, to well-being or to whatever the proclaimed goal of the respective tradition is? Are different practices best suited for different people? To answer these questions, we need more information about the specifics, about the idiosyncrasies of each practice. In this thesis, the looking glass is pointed at the electric activity of the brain during different meditation practices. The studies presented in chapter 2 investigate in depth several different meditation practices. This section gives a brief review of the existing literature. In the following two sub-sections I shall review studies directly comparing different meditation practices and studies that compare meditation against no-task resting.

1.3.1.1. Comparisons between meditation practices

Many meditation practices can be classified as either focused attention meditation (FA) or as open monitoring meditation (OM) based on their narrow focus of attention in the former and their wide open focus of attention in the latter (Lutz, Slagter et al. 2008). Other terms have been used, as for example concentration meditation versus mindfulness meditation. Also additional classes have been defined: automatic self-transcending or non-directive meditation. Several such classification systems of meditation practices have been proposed in the past and we'll have a closer look at these taxonomies in section 1.3.2. and in the general discussion in section 3.3. I mention these distinctions at this point, because some of the studies reviewed in this section make use of these distinctions.

Direct comparisons between different meditation practices have been reported in the past. Early on, the EEG was described in 2 subjects practicing Zazen and 1 subject practicing some unspecified yoga practice (Etevenon, Henrotte et al. 1973). While not directly compared, the description of the observed EEG differed between the two practices, Zazen showing consistent and increased alpha activity, yoga showing intermittent delta increases and dominant alpha and theta activity. Benson et al. (1990) measured metabolic changes and recorded EEG in three Tibetan Buddhist monks. The monks were performing two different meditations and a resting condition, the latter also being a kind of meditation, since the monks felt that it was impossible not to meditate while resting. Metabolic changes were striking and different in the two meditations: metabolism was raised for two subjects in a ‘stabilization meditation’ and raised even more in a ‘g Tum-mo’ meditation. In the third subject the metabolism was decreased in ‘g Tum-mo’ and decreased even more in ‘stabilization’ as compared to the resting condition. The authors believe that this third subject might have performed a different kind of meditation. EEG analysis was possible for two subjects only. There were individual changes in EEG asymmetry and band power, but the differences between the meditations remain unclear. In a study (Lou, Kjaer et al. 1999) with nine Yoga practitioners performing a Yoga Nidra (relaxation) meditation that consisted of different verbally guided parts (experience of weight of body parts, experience of joy and happiness, visualization of summer landscape, abstract perception of self) and silent and auditory control conditions, the EEG was recorded in all subjects, whereas PET (cerebral blood flow, CBF) was used in only two subjects. The authors reported characteristic local activity patterns during the different meditation parts, while global CBF remained unchanged throughout the investigation in both subjects. Dunn et al. (1999) provided ten students with two 5-week courses, one training mindfulness, the other training concentration meditation. The authors found scalp EEG power differences between mindfulness meditation and concentration meditation, e.g. increased delta (frontal and posterior), theta (frontal), alpha (central/posterior) and beta-1 (frontal, central and posterior) frequency band power in mindfulness compared to concentration. The authors tentatively suggest that the inhibitory slow frequency band increases during mindfulness reflect the increased relaxation and calmness, while the increase in excitatory fast frequency bands reflect the simultaneously increased alert wakefulness during mindfulness meditation. In a single-case EEG-based study on a very experienced Tibetan Buddhist meditator (Lehmann, Faber et al. 2001), 4 different meditation practices were compared with source localization using low resolution brain electromagnetic tomography (LORETA). EEG gamma frequency band activity differed significantly between practices in brain areas subserving the cognitive processing required by each practice. Thus, gamma band activity was increased during visualization compared to the other practices in right posterior areas, during verbalization (internal mantra recitation) in left central areas and during self-dissolution and –reconstitution in right fronto-temporal areas. This shows that brain activations during meditative states are content-specific. DeLuca & Daly (2004) also reported qEEG (also using LORETA) differences during several different Tibetan Buddhist meditation techniques performed by one experienced meditator. The direct comparison between emptiness and compassion meditation revealed higher activity for emptiness in the right amygdala and parahippocampus (delta), right middle and superior temporal areas (theta, alpha-1), bilateral temporal areas (beta), wheras compassion meditation showed higher activity in the bilateral middle temporal gyrus (delta), the bilateral anterior cingulate and medial frontal area (theta), the bilateral lingual area (alpha-2), the right temporal and inferior frontal areas (beta-1) and left middle frontal (beta-2). In a study using functional magnetic resonance imaging (fMRI), 8 very experienced Theravada Buddhist monks performed FA and OM meditations which were then directly compared (Manna, Raffone et al. 2010). OM had higher activations than FA in the left hemisphere including the dorsolateral prefrontal cortex (DLPFC), the lateral anterior prefrontal cortex (PFC), the medial frontal gyrus, precuneus, superior parietal lobule (SPL) and the anterior insula. The right hemisphere showed higher OM activations in the anterior PFC (BA10), the inferior frontal gyrus and the transverse temporal gyrus (BA41). Most of these higher activations actually resulted from a decrease in FA rather than an increase in OM, as comparisons to resting revealed. The right hemisphere also showed OM deactivations in the dorsal anterior cingulate cortex (ACC) and the medial anterior PFC. Acem meditation was studied in 14 experienced subjects using fMRI (Xu, Vik et al. 2014). The meditators were recorded while performing a nondirective practice (mental repetition of a simple sound, mind wandering is allowed) and a concentrative practice (sound repetition more forceful and with strict regularity). Nondirective meditation showed higher activations compared to concentrative meditation in the right temporal lobe (middle and inferior temporal gyrus, fusiform gyrus, amygdala and parahippocampal gyrus). Hinterberger, Schmidt et al. (2014) had a group of 30 very experienced meditators from different traditions enter four different states: presence/monitoring (high presence in the moment), thoughtless emptiness (TE), focused attention (attention focused between eyebrows) and spatial connectedness (feeling an energy stream through the body into the earth and the sky). Scalp power spectral density (PSD) was evaluated and compared between states. The authors were especially interested in TE, therefore they contrasted TE against the other three states. Compared to presence/monitoring, TE showed decreased activation in all or several sites on the scalp in the alpha, beta-1, beta-2 and gamma band. Compared to focused attention, TE showed decreased gamma activity at central and parietal sites. TE did not differ significantly from spatial connectedness. Marzetti et al. (2014) used magnetoencephalography (MEG) to compare FA and OM meditations in 8 Theravada Budhist monks, experts in both meditation practices. The authors investigated the coupling of the posterior cingulate cortex (PCC) with the rest of the brain. They found stronger alpha band connections during OM compared to FA between left hemispheric DMN regions and the executive fronto-parietal network (FP), as well as between the left superior frontal gyrus and the FP. The authors propose that the former relates to a higher occurrence of thoughts and images and the latter to higher meta-awareness of these mentations during OM.

In sum, it is clear that there are many differences between meditation practices. The use of different analysis methods, subject groups differing in meditation experience and comparisons between different sets of meditation practices make it difficult though to integrate all the reported findings into a coherent whole. Nevertheless it is important to continue to gather such idiosyncratic knowledge and in time patterns will emerge that will help to better understand the peculiarities and commonalities of the different practices. Study I presented in chapter 2 follows this tradition of directly comparing different meditation practices, focusing on the two Qigong practices of 'Thinking of Nothing' and 'Qigong'.

In the following section, I'll briefly review studies that compare different meditation practices with no-task resting.

1.3.1.2. Comparisons between meditation practices and resting

Comparisons between meditation practices and no-task resting are more abundant than direct comparisons between practices. The following non-exhaustive review follows a roughly chronological order.

In an early EEG-study (Anand, Chhina et al. 1961), 4 Raja Yoga practitioners were recorded during Samadhi. They showed increased alpha activity during meditation. In a combined PET and EEG study (Lou, Kjaer et al. 1999), Yoga Nidra relaxation meditation was compared to resting. In addition, meditations with different content were verbally induced: experience of weight of different body parts, experience of joy, visualization of landscape and abstract perception of self as golden egg. During meditation EEG theta band activity increased in all derivations. CBF differences (assessed for two subjects) between the different meditation states and resting were content-specific: attention to weight perception showed increased CBF in parietal and superior frontal areas, experience of joy in left parietal and superior temporal areas, visualization in occipital and parietal areas. Most meditative states showed increased bilateral hippocampal activations. Phase synchrony was studied in 15 experienced practitioners of TM during meditation and resting (Hebert, Lehmann et al. 2005). Alpha phase synchrony increased during meditation between frontal and occipito-parietal areas. This was not seen in a meditation-naïve control group. In a single case study with a Zen-master, resting was compared to deep meditation using EEG frequency band analysis (Coromaldi, Stadler et al. 2006). Meditation yielded distributed negative correlations between delta and theta activity predominantly right-hemispheric. Resting on the other hand yielded only a few positive delta-theta correlations, but a strong intrahemispheric alpha-beta correlation left posterior as well as central and posterior interhemispheric positive alpha-beta correlations. Meditation yielded only a few alpha-beta correlations mostly connected to frontal locations. Near-infrared spectroscopy (NIRS) and EEG (3 sites: Cz, Pz, Oz) were recorded in novices during the Zen meditation practice of focused attention on Tanden (lower abdomen) breathing and compared to resting (Yu, Fumoto et al. 2011). The authors were specifically interested in PFC activity as an attention-related brain area. Oxygenated hemoglobin increased in the PFC during meditation. Scalp EEG frequency band analysis showed that alpha activity was increased while theta activity was decreased during and after meditation as compared to resting before meditation. The PFC is a structure likely to be involved in many meditation practices (cf. section 1.3.3.). Berkovich-Ohana, Glicksohn and Goldstein (2012) studied 36 practitioners of mindfulness meditation and reported that meditation yielded increased gamma frequency band power over left temporal and parieto-occipital sites as well as right central, temporal and parieto-occipital sites compared to resting. The same authors reported that EEG functional connectivity (measured as mean phase coherence) studied in 36 practitioners of mindfulness meditation increased in the alpha frequency band during meditation as compared to resting in the left hemisphere (Berkovich-Ohana, Glicksohn et al. 2013). In an fMRI study (Josipovic, Dinstein et al. 2012), 22 Buddhist meditators performed three conditions: resting (gazing at a fixation point), FA meditation (focusing on the fixation point) and non-dual awareness meditation (NDA; being equally aware of internal and external events without interfering). The authors studied the anti-correlation of the instrinsic (including precuneus, inferior parietal lobule and medial PFC) and extrinsic (sensory, attention and motor areas) brain systems that process external stimuli less or more respectively. The anti-correlation between the two systems was stronger in FA and weaker in NDA compared to resting.

These two networks will also be of general interest in section1.3.3. looking more closely at brain networks involved in meditation. Functional connectivity in resting state networks was studied in a group of 7 meditators proficient in mindfulness meditation and Hatha Yoga (Froeliger, Garland et al. 2012). Meditation was compared to rest and showed increased functional connectivity between the dorsal attention network and DMN and salience network whereas functional connectivity between the dorsal attention network, dorsal medial PFC, and insula decreased. Functional connectivity increased with years of experience between dorsal attention network, thalamus and anterior parietal sulcus and it decreased between dorsal attention network, lateral and superior parietal and insula. Hasenkamp and Barsalou (2012) also reported increased functional connectivity in resting within attentional networks and between attention related areas and medial frontal areas when comparing practitioners with high meditation experience with practitioners with low meditation experience. This indicates that the strengthening of functional connectivity during mindfulness meditation is transferred into everyday life with increasing experience. In a single-case study a very experienced meditator performed a breath meditation and the progression through the meditation session (mean over 10 sessions) from light to advanced deep meditation was compared to resting (Tsai, Jou et al. 2013). The meditator consistently reported feelings of bliss and self-dissolution during deep meditation. The authors investigated alpha and theta activity with two bipolar derivations (Fp1 – Oz, Fp2 – Oz). During beginning phases of breath meditation, only theta increased bilaterally. During advanced phases, both theta and alpha activity increased significantly compared to resting. The authors conclude that early stages of breath meditation are characterized by internalized attention (theta increase) followed by additional relaxation (alpha increase) during later phases. In an fMRI-study, Xu et al. (2014) had 14 experienced practitioners of Acem meditation perform a nondirective practice (mental repetition of a simple sound, mind wandering is allowed) and a concentrative practice (more forceful and strictly rhythmic mental sound repetition) as well as a no-task resting condition. Compared to resting, the non-directive practice showed increased activity in all default mode network (DMN) areas including orbitofrontal, motor, somatosensory, visual, association, and limbic areas, whereas the concentrative practice showed increased activity in motor and visual areas as well as the bilateral dorsal ACC, with only the latter being part of the DMN. In yet another study, 30 very experienced meditators practicing thoughtless emptiness showed globally decreased delta activity compared to a no-task resting condition (Hinterberger, Schmidt et al. 2014). Also theta was globally (except prefontal areas) decreased. Beta-1 decreased frontal and central, beta-2 in frontal and central midline areas and parietal regions. Also a presence/monitoring meditation condition was performed by the same meditators and compared to resting (Hinterberger, Schmidt et al. 2014). Here delta and theta activity also decreased globally (except theta frontal), alpha increased globally (except central) and gamma increased right temporal during meditation. When studying connectivity in a group of 8 Theravada Buddhist monks, FA and OM meditation both revealed an overall reduced connectivity (Marzetti, Di Lanzo et al. 2014). FA compared to resting showed reduced engagement of bilateral superior frontal gyrus, left middle superior frontal gyrus and lateral temporal cortex and bilateral ACC. OM on the other hand showed increased connectedness between PCC and left intraparietal sulcus compared to resting. Reduced functional connectivity was also reported in non-meditators performing breath-counting, a typical meditation practice (Milz, Faber et al. 2014) compared to resting. The reduced lagged coherences during breath-counting involved bilateral anterior PFC and right somatosensory and visual cortex as well as the right supramarginal gyrus (BA40).

Again, it is difficult to assemble all these findings into a coherent whole. Too different are the practices, the analysis methods and the subject groups to easily bring together the reported results (see also Cahn and Polich 2006). Nevertheless, it is important to continue gathering results from comparisons of different pratices with resting. Hopefully, at some point in the future, all the available results will yield some new insights. Section 1.3.3. contains some examples of meta-analyses trying to bring these results together. Study II presented in chapter 2 follows the tradition of comparing meditation to no-task resting. The meditation practice studied is Zazen, the main Zen meditation practice.

While this section briefly reviewed findings concerning the idiosyncrasies of functional brain data related to different meditation practices, the next section focuses on the possible commonalities of functional brain data of different meditation practices.

1.3.2. Commonalities

> Unfortunately, all too often in our pride
> we have emphasized our conceptual
> differences rather than celebrated our
> common experience.
>
> (Pennington 2006)

Despite all the differences of the existing meditation practices, descriptions of deep states of meditation across traditions and practices seem to suggest a common subjective state of mind.

Words such as ego-dissolution, emptiness, all-oneness, transcendence or bliss are used across traditions. It has been proposed that all the different meditation practices might share the same goal of cultivating a certain state of mind (Bærentsen, Stødkilde-Jørgensen et al. 2010) best described as nondual awareness (Josipovic 2013). See also Berman and Stevens (2015) for a brief review on the terminology. The ultimate goal of all meditation traditions and practices has been described as reaching an 'awakened', 'liberated', or 'enlightened' state (Schwartz and Clark 2006). Since this deepest meditation state transcends the conceptual mind, it is impossible to describe. All the words listed above are merely approximate descriptions of this state. In the Yoga traditions it is believed that during these states, the practitioner is in touch with "Reality" (Feuerstein 2006). On a side note, Edmund Husserl postulated that a special state of consciousness is needed to grasp reality as it is and he called this state "epoché" (Walach 2014). This state of mind is defined by "abstaining from judgment, being with our experience without pre-determining anything through theory" (Walach 2014, p. 12). Walach likens this to the witness consciousness or mindfulness of Eastern traditions.

Considering the similar descriptions of states of deep meditation reached via different meditation practices, the question arises whether the different practices share some brain electric commonalities and thus foster a similar/same deep state of meditation or whether they reach the same goal via different routes. Another open question is whether the final deep states, apparently sharing common subjective experiences, indeed share common brain electric mechanisms. In other words, do the practices already share some brain-electric commonalities or do only (if at all) the achieved deep meditation states share some commonalities?

Irrespective of the depth of the achieved meditation state, meditation practices can be clustered in different ways. Several classification attempts in the past highlight this search for commonalities in different meditation practices. Early classification proposals related to a trophotropic-ergotropic or hypoarousal-hyperarousal dimension (Fischer 1971, Kiely and Gellhorn 1972). The trophotropic or hypoarousal part also called perception-meditation as opposed to the perception-hallucination (ergotropic, hyperarousal) part, harbours most meditation practices. E.g. Zen with the goal of ego-dissolution belongs to the trophotropic side of the scale representing a lowered metabolic or arousal state. Yoga masters seek emptiness, nothingness, the Void, a state which belongs to the lowest metabolic or arousal (throphotropic) end of the dimension (Fischer 1976). On a side note, it is unclear whether this distinction between Zen and Yoga holds, since for both the desired deep end states share an aspect of non-duality. Later, based on Buddhist traditions of meditation, and focusing more on the attention dimension, other classifications were proposed: the concentration versus mindfulness classification (Davidson and Goleman 1977) and the nowadays very popular focused attention (FA) versus open monitoring classification (OM) (Dunn, Hartigan et al. 1999, Lutz, Slagter et al. 2008, Raffone and Srinivasan 2010). The distinction made in these classifications concerns the focus of attention, which is narrow in concentration/focused attention meditations and wide/open in mindfulness/open monitoring meditations. Based on brain electric findings, Travis and Shear (2010) added automatic self-transcending to the FA and OM classification as a third category. The practice of internally focusing on a meaningless mantra falls into this category and is characterized by increased alpha activity. Another practice that might fit in this category of automatic self-transcending is the very similar Acem meditation practice of mentally repeating a simple sound and, like TM, also allowing mind wandering. Self-transcending has also been termed nondirective meditation (Xu, Vik et al. 2014) or non-dual awareness (Josipovic, Dinstein et al. 2012). In section 3.3. of the general discussion, I shall take up the subject of taxonomies once more and discuss their limitations and problems.

Some rare studies searched for commonalities between different meditation practices and they are briefly reviewed in the following sub-section.

1.3.2.1. Known commonalities

Not much is known about brain functional commonalities across meditation traditions and practices. Travis and Shear base their taxonomy of meditation practices on brain electric findings (Travis and Shear 2010). According to their review, open monitoring (OM) meditations show increased EEG theta frequency band (5-8 Hz) activity. Focused attention (FA) meditations are characterized by increased EEG gamma (30-50 Hz) and beta-2 (20-30 Hz) frequency band activity. Automatic self-transcending displays increased EEG alpha-1 (8-10 Hz) frequency band activity. Some theoretical assumptions about the brain networks involved in different classes of practices are derived from other taxonomies and will be the topic of section 1.3.3.

Apart from classification attempts, the direct study of commonalities of different practices has been rare. An early such study was conducted by Becker and Shapiro (1981). They analyzed the EEG alpha suppression, the ERP N100, P200 and P300 components and the skin conductance, all in response to clicks administered via headphones, in three groups of meditators: Yoga (mantra meditation), Zen (Zazen) and TM (mantra meditation). No differences between the groups were found in their responses to the clicks. All groups habituated similarly to the clicks. This study contradicts two earlier studies reporting no habituation to clicks in a yoga group (Anand, Chhina et al. 1961) and a Zen group (Kasamatsu and Hirai 1966).

Khare and Nigam (2000) studied 15 meditators practicing TM and 15 meditators practicing yogic meditation and a group of 10 control subjects. They found significant EEG differences between both groups of meditators (during meditation) and control subjects (during relaxed resting). Frontal alpha percentage increased during meditation, alpha coherence decreased during meditation. Unfortunately, the authors do not report any results that might distinguish between the two meditation groups.

In a study by Tooley et al. (2000), both TM practitioners of the Sidhi program (advanced practices of TM) and advanced Yoga practitioners showed increased melatonin levels directly following meditation. How exactly this common effect is produced and if the underlying mechanisms are the same remains unclear though.

In a pilot study, Faber et al. (2005) investigated EEG microstate parameters (see also section 1.4.3.) in three meditators of different groups (Tibetan Buddhism, Ch'an Buddhism, Theravada Buddhism), performing self-dissolution, Ch'an Mo'chao, and Vipassana respectively. The authors report a longer duration of EEG microstate class 'B' during meditation in all three subjects as compared to a normative database of non-meditators (Koenig et al. 2002). During resting, the meditators did not show this difference. This is interesting as the same class 'B' microstate is known to have a shortened duration in schizophrenics (e.g. Koenig, Lehmann et al. 1999, Strelets, Faber et al. 2003, Lehmann, Faber et al. 2005).

Using blood-oxygen-level dependent (BOLD) contrast imaging, experienced meditators were compared to meditation-naïve controls during the three meditation practices of concentration on breathing, loving-kindness and choiceless awareness (Brewer, Worhunsky et al. 2011). Across all meditation practices the medial prefrontal cortex and the posterior cingulate cortex, two main nodes of the DMN showed reduced activation compared to controls, who also performed these meditations. Also the functional connectivity between the PCC, the dorsal ACC and the dorsolateral PFC was increased during meditation. The authors relate these findings to reduced mind-wandering during meditation.

Berman and Stevens (2015) recorded the EEG of 44 meditators during very different practices including TM, Vipassana or Mindfulness meditation, breath/body awareness, mantra meditation and visualization. The subjects had to signal by winking with their left eye whenever they noticed that they had exited a state of non-thought (i.e. transcendence, mental silence, or non-duality). For the 20 subjects clearly signaling non-dual events, the 30 seconds before the signal (nonduality) were compared to the 30 seconds after the signal and to the whole meditation session. Non-dual states only showed significant differences against the whole session: delta, theta and alpha band power increased while beta and gamma band power decreased during non-dual states.

Very different practices and states have been compared using different methods and again the results do not paint a simple picture. It appears that EEG commonalities between meditation practices of different meditation traditions have yet to be studied in more depth. Study III presented in chapter 2 investigates brain electric commonalities of deep meditation states achieved through different practices. The rationale here is – as already mentioned at the beginning of this section – that there must be some commonalities since the subjective experiences are described in similar words across traditions and practices.

1.3.3. Brain networks involved in meditation

While simple frequency band analyses have dominated the earlier meditation studies, the development of new imaging methods lead to the increasing popularity of investigating distributed brain networks. The search for brain networks involved in meditation is still a hot topic. Some meta-analyses were conducted with the hope of disentangling the diverse findings reported over the years. Let us have a quick look at what was found.

Because most meditative practices induce relaxation, regulate attention and foster detachment from thoughts, Sperduti, Martinelli et al. (2012) hypothesized that most practices share a central process supported by a core network. They conducted a meta-analysis of 10 previous meditation studies of different practices, including different Yoga practices, Acem, mindfulness, focused attention and Tibetan Buddhist meditation. They found activation in the basal ganglia (left caudate body), the limbic system (left enthorinal cortex) and the MPFC. They attributed the activation of the caudate body to behavior control, i.e. the reduced distractability by irrelevant stimuli during meditation. The activity in the enthorinal cortex was proposed to relate to monitoring of ongoing experience and the evaluation of their relevance. The MPFC as part of the DMN has been related to self-reflection and might reflect the inward shift of attention. While it is interesting that these core regions were activated across very different practices and that only expert meditators were used, it must be kept in mind that the evaluated studies do not cover practices favouring increased arousal rather than relaxation. Also, as the authors themselves note (Sperduti, Martinelli et al. 2012), less experienced meditators might engage different networks.

Tomasino, Chiesa and Fabbro (2014) searched for commonalities in Hinduism-related practices and Buddhism-related practices. Practices from Hinduism usually target nothingness, a state of selflessness and non-duality. Buddhist practices on the other hand usually target a state of mindfulness by sustained focused attention on body, breathing and thoughts. The authors conducted meta-analyses of fMRI studies on Hinduism (8 experiments) and Buddhism-related practices (16 experiments). Common to Buddhism-related practices were activations in the bilateral frontal superior medial gyrus, the right supramarginal gyrus (SMG) and the supplementary motor area. Common to Hinduism-related practices were left lateralized activations in the superior parietal lobe, the hippocampus and left superior temporal gyrus as well as activations in the right middle cingulate cortex. Tomasino, Fregona et al. (2013) performed another set of meta-analyses searching for networks related to FA practices, to practices using mantra repetitions and to meditation expertise. A meta-analysis conducted over all practices yielded a network consisting of bilateral frontal and parietal areas and the right insula. FA practices showed activations in the bilateral medial gyrus, the left superior parietal lobe, the left insula and the right SMG. Mantra practices activated the right SMG, bilateral supplementary motor area and left postcentral gyrus. Experience in meditation also played a role: over all practices, short-term meditators showed more frontal activations compared to long-term meditators.

The categories selected in the previous meta-analyses (Tomasino, Fregona et al. 2013, Tomasino, Chiesa et al. 2014) seem a bit arbitrary as does the selection of practices in the study by Sperduti et al. (2012). A possibly more fruitful approach is based on reported subjective experiences during meditation and more theoretical considerations about the cognitive and attentional processes involved. Let us have a look at which brain networks are likely to be affected by the practice of meditation.

For one, there is the intrinsic, task-negative or default mode network (DMN; Raichle, MacLeod et al. 2001), which is active at rest without task. It encompasses the following brain areas: the dorsal and ventral medial PFC, the PCC and precuneus, posterior inferior parietal regions, lateral temporal cortex, and the hippocampus including the parahippocampus (Gusnard, Akbudak et al. 2001, Raichle, MacLeod et al. 2001, Buckner, Andrews‐Hanna et al. 2008). DMN activation has been strongly related to several cognitive processes affected by meditation: mind wandering (Mason, Norton et al. 2007), episodic memories (Greicius, Srivastava et al. 2004, Buckner, Andrews‐Hanna et al. 2008) and conceptual processing (Binder, Frost et al. 1999). These are all important for maintaining the sense of self (Gusnard, Akbudak et al. 2001, Lou, Luber et al. 2004). All meditation practices reduce mind wandering and weaken the sense of self and thus should produce a deactivation of parts of the DMN.

Then there is the extrinsic or task-positive network, activated by tasks demanding attention to external stimuli. It consists of the following brain areas: the lateral PFC, the premotor cortex, lateral parietal regions, occipital regions, the ACC and the insula (Fox, Snyder et al. 2005).

These regions have been strongly implicated in various aspects of attention (Posner and Petersen 1989, Corbetta, Patel et al. 2008). Attention plays a paramount role in many meditation practices, as the popular distinction between FA and OM shows.

Activity in the task-positive and task-negative network is anticorrelated (Fox, Snyder et al. 2005, Fukunaga, Horovitz et al. 2006). It has been speculated that this anticorrelation might reflect the duality of self-related internal and other-related external mentation (Josipovic 2014). The authors report a decrease of this anticorrelation during meditation states of non-duality.

It is reasonable to assume that FA meditation activates part of the attention-related task-positive network. Hasenkamp et al. (2012) had a closer look at the attentional mechanisms involved in the practice of FA. They distinguish four phases occurring during the practice of focused attention: 1. mind wandering, 2. awareness of mind wandering, 3. shifting of attention back to the object of focus, and 4. sustained attention on the focused object. The authors studied 14 meditators during FA on breathing. The meditators were asked to press a button whenever they noticed that they had been completely off the breath. Their task was then to shift their focus back on the sensations of breathing. The 3 seconds surrounding the button press were attributed to phase 2, the 3 seconds before that to phase 1, the 3 seconds following phase 2 were considered phase 3 and the following 3 seconds were phase 4. Phases 2, 3 and 4 showed activations in the task-positive network. The activations of these 3 phases were consistent with subdivisions of the attention network. Phase 2 (awareness of mind wandering) activated the salience network (bilateral anterior insula and dorsal ACC), phase 3 (shifting attention back to breathing) activated the executive network (lateral dorsal and ventral PFC, the lateral inferior parietal cortex, predominantly right-sided) and phase 4 (sustained attention) kept a cluster of the executive network (DLPFC) activated. Phase 1 (mind wandering) on the other hand activated the task-negative network or DMN (PCC, medial PFC, posterior parietal/temporal cortex, parahippocampal gyrus). This study is very interesting because it highlights the importance of a temporally more fine-grained study of the processes underlying the practice of meditation. That is precisely why the next section includes a subsection on EEG microstate analysis (1.4.3.) that seems especially promising for this kind of fine-grained analysis.

Malinowski (2013) nicely described the meditation process of FA on three levels: phenomenology, attention processes and brain networks. He distinguished 5 processes, expanding phases 3 and 4 of Hasenkamp et al. (2012) into a process of disengagement from mind wandering, a reorienting back to the object of focus and an alerting process sustaining the attention on the object. Accordingly Malinowski hypothesizes 5 involved brain networks: an alerting network (sustaining attention on focused object), the DMN (mind wandering), the salience network (monitoring awareness and detecting mind wandering), the executive network (disengaging from mind wandering) and the orienting network (reorientation to object of attention).

On a side note, it is unclear how states of non-duality, of transcendence, that were proposed to lie outside the classification separating FA and OM meditations (Josipovic 2010), are related to the proposed involvement of these networks. As mentioned before, first results suggest that during states of nondual awareness, the anticorrelation between intrinsic and extrinsic networks is reduced (Josipovic 2014).

Corbetta and Shulman (2002) proposed two attention networks: a right-lateralized ventral fronto-parietal network and a bilateral dorsal fronto-parietal network. The ventral network includes the temporoparietal junction (TPJ), the ventral prefrontal cortex (vPFC) and the anterior insula. The dorsal network includes the dorsal parietal cortex (particularly the intraparietal sulcus and the superior parietal lobule), and the frontal eye field. The dorsal network seems negatively correlated with the DMN (Corbetta, Patel et al. 2008). Reorienting needs the interaction of both networks. During focused attention, the ventral network is suppressed and reorienting towards distracting stimuli is interrupted.

In the general discussion (chapter 3), I will try to relate the results of the three studies presented in chapter 2 to these proposed networks.

1.4. Methods

States of consciousness can be studied via the underlying brain mechanisms. Electroencephalography (EEG) is one method for analyzing brain states. It has several advantages over other methods (Ozaki and Lehmann 2000). It is completely non-invasive and very low-cost. It has a very high time resolution and it is extremely sensitive to central nervous system state changes. Two of the methods described in this section (intracortical source modeling and intracortical lagged connectivity) were used in the studies presented in chapter 2 of this thesis and were used for the analysis of multi-channel EEG data. One presented method, the EEG microstate analysis is included because it seems a promising method for a more fine-grained analysis of the processes involved in meditation and I will discuss its possible merits for the study of meditation in the general discussion (chapter 3).

1.4.1. Intracortical source modeling

The electroencephalogram (EEG) represents the electric activity of the brain measured as potential differences between electrodes on the scalp. The so-called ‘inverse problem’ consists of estimating the exact location of the sources in the brain that underlie the electric activity that can be measured on the scalp. In other words, where is the origin of the electrical activity that we measure on the scalp? This inverse problem has an infinite number of solutions. The simplest solution, the non-weighted minimum norm solution (Hämäläinen and Ilmoniemi 1984) has been shown to have bad localization properties: it places deep sources too close to the surface (Pascual-Marqui 1999). Solutions to the inverse problem need certain constraints to yield better results. Low resolution brain electromagnetic tomography (LORETA, Pascual-Marqui, Michel et al. 1994, Pascual-Marqui, Lehmann et al. 1999, Pascual-Marqui, Esslen et al. 2002) is another solution to the inverse problem. As constraint it uses spatial smoothness, i.e. it forces a solution where neighboring voxels in the solution space behave most similar, i.e. the current density of a voxel must be most similar to that of its neighboring voxels. This is based on the idea that physiologically, neighboring neurons are most likely to be active synchronously and simultaneously (Hämäläinen, Hari et al. 1993). Through enforcing smoothness, the algorithm of course sacrifices spatial resolution, hence the ‘low’ resolution of the solution. Thus, LORETA computes the 3-dimensional intracortical localizations of the brain electric generators that are the source of the potential distribution measured on the scalp and it finds the best possible solution based on the above smoothness constraint. LORETA does not use any a priori assumptions about number, location or orientation of the generators. LORETA’s solution space covers the cortical gray matter and hippocampus and consists of 2394 voxels at 7 mm resolution. On a side note, LORETA solutions are independent from the chosen recording reference.

Standardized LORETA (sLORETA,) is an enhancement of the original LORETA in that it yields images of standardized current density with zero localization error (Pascual-Marqui 2002). It solves the problem of deep source misplacement of the minimum norm inverse solution by statistical standardization of the minimum norm current density estimates and basing its localization inferences on these standardized estimates (Pascual-Marqui 2002). In doing so, it produces exact (zero-error) localizations. The solution space of sLORETA consists of 6239 cortical gray matter voxels (5 mm resolution) in a realistic head model (Fuchs, Kastner et al. 2002), using the MNI152 template (Mazziotta, Toga et al. 2001).

LORETA has been very well validated (for a review, see Pascual-Marqui, Esslen et al. 2002). And the validation for sLORETA with its improved (zero-error) localization mostly rests upon the published LORETA validations. Some more recent papers also directly validate sLORETA (Betting, Li et al. 2010, Laxton, Tang - Wai et al. 2010, Plummer, Wagner et al. 2010, Dümpelmann, Ball et al. 2012).

In the studies presented in chapter 2 of this thesis, sLORETA was used for analysis.

1.4.2. Intracortical lagged connectivity

Classical coherence is computed between EEG-signals measured on the scalp. This has several disadvantages. Since neuronal electric sources do not necessarily project radially to the scalp, conventionally computed EEG coherence does not necessarily reveal true functional connectivity between the brain regions under the recording electrodes. This problem can be solved by computing EEG coherence between intracerebral generator model sources (see also Ruchkin 2005). Another issue with conventional scalp signal based coherence computation is volume conduction that produces non-physiological coherence values with zero phase lag between data time series and thus leads to unduly inflated coherence. This confounding effect of volume conduction can be avoided by omitting the zero phase angle coherence values (Nolte, Bai et al. 2004). A third problem arises from the fact that the waveform of an EEG time series recorded from a head surface electrode depends on the chosen reference, which makes conventional head surface coherence reference-dependent (Lehmann, Faber et al. 2006). Computing coherence between reference-independent source model-generated time series solves this problem.

Study III presented in chapter 2 uses an analysis method exempt of the three problems inherent in conventional head surface based coherence computation. The computation of intracortical functional connectivity used in study III computes coherence between cortical time series of electric neuronal generator activity estimated via LORETA-based source modeling (see previous section 1.4.1.) of head-surface recorded EEG data (sLORETA, Pascual-Marqui 2002). This solves the problem of reference-dependence and it removes the ambiguity of source localization. To solve the problem of unduly inflated coherence values based on volume conduction, the analysis applies ‘lagged’ coherence that partials out the effect of zero phase angle coherence (Pascual-Marqui 2007, Pascual-Marqui, Lehmann et al. 2011).

LORETA-based intracortical lagged connectivity has successfully been used in several studies. For example it was used for investigating functional connectivity during autobiographical memory retrieval (Imperatori, Brunetti et al. 2014), during breath counting – a classical meditation practice – in non-meditators (Milz, Faber et al. 2014), and to compare schizophrenics with normal controls (Lehmann, Faber et al. 2014).

1.4.3. EEG Microstate analysis

Changes of the brain's functional state are associated with changes of the brain's electrical activity as recorded from the human head surface (electroencephalogram, 'EEG' or event-related potentials, 'ERPs'). A classical example is the change from wakefulness to sleep.

Brain electric activity can be parsed into brief, split second ‘microstates’ ('micro-states') that are defined by quasi-stable spatial distributions (landscapes) of the electric potential, and that are concatenated by quick changes in landscapes (Lehmann, Ozaki et al. 1987, Lehmann, Strik et al. 1998). Because different landscapes of brain electric potential must have been generated by different spatial distributions of neuronal electric activity in the brain, it is reasonable to assume that different microstates embody different types of information processing. The mean duration of microstates ranges from about 70 to 125 ms. This time range is relevant for the postulated ‘elementary deliberations’ (Newell 1992) and for useful interaction with the environment.

In 'spontaneous' EEG recordings of normal participants during a 'no-task' condition with closed eyes, four standard classes of microstates (showing different landscapes of electric potential) are distinguished; the parameters of the microstates (e.g. duration, occurrences per second, covered percentage of analysis time) changed as function of age (Koenig, Prichep et al. 2002). Spontaneous mentation which contains visual imagery compared to abstract thinking was associated with two different EEG microstate classes immediately before the reported mentation (Lehmann, Strik et al. 1998). Event-related microstates differed when reading imagery compared to abstract words (Koenig, Kochi et al. 1998). A conjunction analysis of the results of these two studies using LORETA tomographic imaging (Pascual-Marqui, Michel et al. 1994) revealed common activated intracerebral brain areas: left anterior for processing of abstract thoughts, and right posterior for processing of imagery mentation (Lehmann, Pascual-Marqui et al. 2010).

Microstate parameters sensitively co-vary with conditions and tasks in healthy people: Microstate durations decreased in deep hypnosis (Katayama, Gianotti et al. 2007), and increased during meditation (Faber, Lehmann et al. 2005). Microstate parameters differed between believers versus skeptics in paranormal phenomena (Schlegel, Lehmann et al. 2012). Cognition-enhancing medication dose-dependently affected microstate topography (Lehmann, Wackermann et al. 1993).

Microstate parameters depend on disease conditions: EEG microstates in medication-naïve, first-episode, productive schizophrenics were shortened in two of the four standard classes

(Lehmann 1990, Koenig, Lehmann et al. 1999, Lehmann, Faber et al. 2005, Irisawa, Isotani et al. 2006). Chronic schizophrenics with positive symptomatology also exhibited shortened microstate duration (Strelets, Faber et al. 2003). The shortening of microstates of certain classes was interpreted as abortive termination of specific types of information processing that result in the schizophrenic symptomatology of loosened associations. Supporting this conclusion, neuroleptic medication increased microstate duration in schizophrenics (Yoshimura, Koenig et al. 2007). In a recent study (Andreou, Faber et al. 2014), high risk individuals were compared to stable first-episode schizophrenics and healthy controls. Microstate class A showed increased coverage and occurrence in the high risk group, microstate class B showed higher coverage in schizophrenics than the other two groups. Shortening of microstate duration along with increased topographical variance was observed in depressive patients (Strik, Dierks et al. 1995).

The syntax of information processing strategies is embodied in the brain electric field by the concatenation of microstates: Transitions between microstates of different classes were different in acutely ill schizophrenic patients compared to normal controls (Lehmann, Faber et al. 2005). Also, healthy believers and skeptics in paranormal phenomena had different rules for the sequencing of microstate classes (Schlegel, Lehmann et al. 2012).

The microstate analysis is included in this section because it is very appealing and very promising for studying the subtleties of different meditation states and the underlying processes. In section 3.5. I'll describe in more detail the possible benefits of using the microstate analysis in meditation research.

2. Studies

In this chapter I present three studies that are concerned with the brain electrical idiosyncrasies and commonalities of different meditation practices from different meditation traditions. While studies I and II describe the specificities of brain electric activity localizations underlying different meditation practices, study III focuses on brain electric commonalities of different meditation practices. All studies have been published (Faber, Lehmann et al. 2012, Lehmann, Faber et al. 2012, Faber, Lehmann et al. 2014).

Specifically, study I analyzes in more depth two common Qigong meditation practices: ‘Thinking of Nothing’ and ‘Qigong’. While the former consists of trying to think of nothing by suppressing intruding thoughts, the latter consists of concentrating on performing slow breath-synchronized arm movements. The study directly compares the brain electric activities underlying the two meditation states and reports the brain areas that differ in their electric activity between the two meditation states and discusses the functional meaning of these differences. The two meditations are also compared to no-task resting.

Study II is also searching for idiosyncrasies and focuses on one classical Zen meditation practice: Zazen. Zazen consists of ‘just sitting’ and letting experiences come and pass without getting attached to them. The study describes in detail the localization of brain electric activity changes that happen during this meditation practice compared to no-task resting.

Study III on the other hand searches for commonalities between deep meditation states achieved by practices from 5 different traditions: Tibetan Buddhism, QiGong, Sahaja Yoga, Ananda Marga Yoga and Zen Buddhism. From each tradition that meditation practice was selected that leads to the deepest optimal state of meditation according to the practitioners of the respective tradition. The study describes the brain electric changes during meditation compared to no-task resting using the measure of intracortical lagged connectivity.

2.1. Study I - EEG source imaging during two Qigong meditations[1]

2.1.1. Abstract

Experienced Qigong meditators who regularly perform the exercises "Thinking of Nothing" and "Qigong" were studied with multichannel EEG source imaging during their meditations. The intracerebral localization of brain electric activity during the two meditation conditions was compared using sLORETA functional EEG tomography. Differences between conditions were assessed using t statistics (corrected for multiple testing) on the normalized and log-transformed current density values of the sLORETA images. In the EEG alpha-2 frequency, 125 voxels differed significantly; all were more active during "Qigong" than "Thinking of Nothing," forming a single cluster in parietal Brodmann areas 5, 7, 31, and 40, all in the right hemisphere. In the EEG beta-1 frequency, 37 voxels differed significantly; all were more active during "Thinking of Nothing" than "Qigong," forming a single cluster in prefrontal Brodmann areas 6, 8, and 9, all in the left hemisphere. Compared to combined initial–final notask resting, "Qigong" showed activation in posterior areas whereas "Thinking of Nothing" showed activation in anterior areas. The stronger activity of posterior (right) parietal areas during "Qigong" and anterior (left) prefrontal areas during "Thinking of Nothing" may reflect a predominance of self-reference, attention and input-centered processing in the "Qigong" meditation, and of control-centered processing in the "Thinking of Nothing" meditation.

2.1.2. Introduction

Meditative states belong to those altered states of consciousness (Tart 1969; Dietrich 2003; Vaitl et al. 2005) that can be reached voluntarily, without drugs, by doing exercises (practices) which have been established in the different traditions of meditation. The traditions use very different repertories of meditation exercises. Moreover, within a given tradition, typically several different exercises are done by the meditators. Different exercises of a given meditation tradition produce meditative states that differ in physiological measures, for example, oxygen uptake "VO2" (Benson et al. 1990), electrocardiogram (Peng et al. 2004), and autonomic patterns (Travis 2001), as well as in psychological measures, for example, pain sensation (Perlman et al. 2010), mood and anxiety (Zeidan et al. 2010), attention (Jha et al. 2007), and subjective experience (Wang et al. 2011).

EEG measures also yielded various differences between different exercises within a given

[1] This study has been published: Faber PL, Lehmann D, Tei S, Tsujiuchi T, Kumano H, Pascual-Marqui RD & Kochi K. (2012). EEG source imaging during two Qigong meditations. Cognitive Processing **13**(3): 255-265.

tradition: in Buddhist meditation (power spectra: Benson et al. 1990; source localization: Lehmann et al. 2001), in mindfulness-concentration meditation (power spectra: Dunn et al. 1999), in Qigong (power spectra: Pan et al. 1994), in Shaolin DanTian breathing (power and coherence: Chan et al. 2011), and in Transcendental Meditation (power spectra, coherence, and source localization: Travis 2001, 2011; Travis et al. 2010; see also Travis and Shear 2010). On the other hand, Sun et al. (1984) reported that there was no difference in results between QiGong exercises. Given the variety of meditation traditions, meditation exercises, and techniques of EEG recording and analysis, the reported results expectedly varied widely (see also Cahn and Polich 2006).

As to EEG studies on QiGong, the eight papers that are available to us show little agreement and some direct contradictions of results during meditation compared to rest or controls. Going through the EEG frequency bands, we note the following: Two of the studies found theta increase (Pan et al. 1994; Minegishi et al. 2009), two found frontal alpha-1 increase (Zhang et al. 1988; Qin et al.2009), one found alpha-2 increase (Minegishi et al. 2009), one found frontal alpha full band increase (Sun et al. 1984), one found occipital alpha full band increase (Lee et al.1997), one found right frontal-temporal alpha full band decrease (Yang et al. 1994), one found beta-1 increase (Minegishi et al. 2009), one found beta-2 increase (Itoh et al. 1996), and one found right frontal-temporal beta full band decrease (Yang et al. 1994). Assuming that all reports concerned the exercise that leads to the optimal meditative state, the irritating lack of agreement partly might be due to different EEG analysis strategies as also mentioned above. Enlarging the result base appears of paramount importance for clarification.

We had the possibility to record EEG from experienced Qigong meditators who regularly perform two exercises of their meditation tradition, doing first "Thinking of Nothing" and thereafter "Qigong" (that involves slow arm movements) to reach the desired optimal meditative states of consciousness. Because the meditators were not willing to reverse their habitual sequence when we proposed such a reversal in order to eliminate sequence effects, we conclude that getting into "Thinking of Nothing" is the prerequisite for doing "Qigong." The latter evidently is the exercise that leads to the desired optimal state of QiGong meditation. This conclusion is supported by the meditators' spontaneous reports that they reached a deeper state of meditation during "Qigong."

We decided to contribute to the collection of brain electric effects of different QiGong exercises by applying the electric source imaging method "Low Resolution Electromagnetic Tomography" (LORETA, Pascual-Marqui 2002; Pascual-Marqui et al. 1994, 2002) to our data in order to determine the intracerebral localization and strength of brain electric activity of inhibiting and facilitating character. LORETA brain electric functional imaging analysis uses intracerebral source modeling and thereby avoids the ambiguities of localization and strength that are inherent in conventional analyses of head-surface EEG data because the latter depends on the chosen reference location.

It would be desirable to classify the two QiGong exercises in a general scheme of meditation states; we note that the exercises of our meditators are only two specific practices of a large number of different sub-traditions and techniques known as QiGong. Early proposals of meditation taxonomies referred to a trophotropic-ergotropic or hypoarousal-hyperarousal axis (Fischer 1971; Gellhorn and Kiely 1972) and did not mention QiGong. Later schemes proposed two or three distinct categories. Based on Buddhist traditions of meditation was the concentration versus mindfulness classification by Davidson and Goleman (1977)—mindfulness was exclusively emphasized by Kabat-Zinn (1982)—and the focused attention versus open monitoring classification (Dunn et al. 1999; Lutz et al. 2008; Raffone and Srinivasan 2010), as well as the concentration—mindfulness—grasping classification by Mikulas (1990); none of these mentioned QiGong. Cahn and Polich (2006) offered a review that distinguished concentration from mindfulness meditation, and accepted Pan et al.'s (1994) report on "concentrative QiGong" as such while concluding that Pan et al.'s "non-concentrative QiGong" must be mindfulness. In fact, Pan et al.'s paper does not give a description of the two meditation exercises beyond their labeling. We note, however, that the Buddhist meditation-based dichotomic or trichotomous schemes do not address the ultimate desired optimal meditation state that has been described across meditation traditions (Fischer 1971; Davidson 1976; Newberg and Iversen 2003) in terms such as all-oneness, bliss, oceanic feeling, transcending, or expanded consciousness. Travis and Shear (2010) include "transcending" in their three-way classification of focused attention, open monitoring, and automatic self-transcending. As to QiGong, however, these authors classify Pan et al.'s (1994) "concentrative QiGong" condition as "open monitoring," contrary to Cahn and Polich's (2006) acceptance of "concentration" (see above) as also done by Baijal and Srinivasan (2010) and Cahn et al. (2010). Travis and Shear's (2010) classification as "open monitoring" is due to their EEG frequency band based three-way classification: gamma and beta-2 indicates focused attention, theta indicates open monitoring, and alpha-1 indicates "automatic self-transcending" as known in Transcendental Meditation. In sum, the overview about classification schemes shows that the minimal attention and the controversial entries about QiGong in the proposed distinctions between meditation techniques does not indicate useful conclusions about our present material (see also Baerentsen et al. 2010).

We analyzed the multichannel EEG recordings obtained from our experienced Qigong meditators during their exercises of “Thinking of Nothing” and “Qigong” and notask resting, using sLORETA functional EEG tomography (Pascual-Marqui 2002; Pascual-Marqui et al. 2002). We compared the intracerebral localization and strength of the sources of brain electric activity during the two meditation exercises and examined how they differed from no-task resting.

We hypothesized (1) that the two meditation states “Thinking of Nothing” and “Qigong” are different in their brain electric signature, (2) that “Qigong” shows activity in motor areas, and (3) that “Thinking of Nothing” and “Qigong” differ from no-task resting in the same direction.

The present study thus aims at providing insights into brain electric mechanisms of different QiGong meditation exercises using the above-mentioned LORETA analysis that yields non-ambiguous results, thereby enlarging a reliable database for future more complete classifications of meditation exercises.

2.1.3. Materials and methods

Participants

Among the members of Master Feng-San Lee’s Qigong Center “Meimen” in Taipei, experienced meditators were invited to participate in the study. During a visit of the meditator group to Tokyo, EEG during meditations could be recorded from 10 meditators; the data of two had to be omitted (technical problems in one case, a strong headache during the recording in the other). Thus, data of eight meditators were available for analysis (mean age: 41.5 years, SD = 10.4, range: 30–56, 3 males, education level: 2 high school, 6 university graduates). The eight meditators had an average meditation experience of 11.5 years (SD = 8.8, range: 3–30), and all meditated regularly for approximately one hour each day.

All meditators were self-declared right-handers and reported no earlier or current psychiatric illness, no head trauma and no drug usage, and they did not take centrally active medication. After receiving complete information about the study, all meditators gave their written consent. The Ethics Committee of The University of Tokyo approved the study (#1364) that follows the standards of the Declaration of Helsinki laid down in 1964.

EEG recording

The EEG was recorded in a room of the hotel where the meditators stayed during their visit to Tokyo. The participants were seated on a comfortable chair. Nineteen EEG electrodes were applied at Fp1/2, F3/4, F7/8, Fz, T3/4, C3/4, Cz, T5/6, P3/4, Pz, O1/2 of the International 10/20 System (Jasper, 1958) using a Neuroscan electrode cap. The EEG recording was done with a portable 24-channel EEG acquisition system (TEAC AP1000). All impedances were kept below 5 kΩ. The left ear was used as a reference for the EEG channels. The EOG was recorded from electrodes at the outer left canthus and under the right eye. One more electrode on the neck recorded muscle activity. Using a recording high pass filter of 0.05 Hz and a low pass filter of 100 Hz, the EEG data were digitized at 200 samples/sec per channel.

Recording conditions

1. Initial Resting (4 min): The task-free eyes-closed resting condition was recorded at the beginning of the recording session: 20 s eyes open, 40 s eyes closed, repeated four times.

The meditators then performed their three standard meditation exercises (Yuasa 1990, p. 114 and p. 136) as described here, followed by a final resting period:

2. Breath Counting (10 min): A preparatory exercise to calm the mind and the body while concentrating on nasal air flow. This preparatory condition was not included in the present analysis.
3. ‘‘Thinking of Nothing’’ (10 min): A meditation exercise. The practitioner is ‘‘Thinking of Nothing.’’ The focus is on trying not to think of anything or feel anything, physically, to let the body relax, and mentally, to try to ‘‘dissolve into emptiness.’’
4. ‘‘Qigong’’ (10 min): A meditation exercise. The practitioner is performing ‘‘Qigong,’’ which means doing slow arm movements in synchrony with his/her breathing while continuing to think of nothing, reaching higher sensory awareness, transcending. The arm movements are done at a very slow rate, as low as about two per minute.
5. Final Resting (4 min): The task-free eyes-closed resting condition was repeated at the end of the recording session: 20 s eyes open, 40 s eyes closed, repeated four times.

The preparatory and meditation conditions were done with closed eyes, following the meditators' daily practice.

The experimenter verbally cued the start and end of each condition.

Data conditioning

EEG data of the resting conditions (1) and (5) and of the meditation conditions (3) and (4) were analyzed. Off-line, the data were parsed into 2-second epochs; all epochs were inspected on a PC screen for eye-, muscle-, and technical artifacts; all artifact-free epochs were selected for analysis. An earlier selection of resting (1) data was used in Tei et al. 2009. An average of

88.6 (SD = 94.4; range: 13–254) 2-second epochs per participant was available for the meditation condition (3), and 91.8 (SD = 80.5; range: 18–230) for meditation condition (4). For initial resting (1), the average was 45.8 epochs (SD = 16.9; range: 30–74) per participant, for final resting (5) 43.1 (SD = 19.0; range: 7–72) epochs.

Frequency band-wise LORETA analysis

Low Resolution Electromagnetic Tomography (LORETA; Pascual-Marqui et al. 1994, 1999, 2002; Pascual-Marqui 2002) solves the inverse problem of computing the 3-dimensional intracortical localizations of the brain electric generators that produced the potential distribution that were measured on the head surface. It does this by finding the smoothest of all possible solutions without using any a priori assumptions as to number, location, or orientation of the generators. Published validation for the LORETA method has shown for instance excellent localization agreement in multimodal imaging studies with functional MRI (Mulert et al. 2004; Vitacco et al. 2002), structural MRI (Worrell et al. 2000), and PET (Dierks et al. 2000; Zumsteg et al. 2005). Also, validation in humans based on accepting the information provided by intracranial recordings as "ground truth" has been reported in several papers (Zumsteg et al. 2006a, b; Yang et al. 2011).

sLORETA (Pascual-Marqui 2002; Pascual-Marqui et al. 2002; available free from http://www.uzh.ch/keyinst/loreta.htm) was used to analyze the head-surface EEG data into brain functional tomographic images. The sLORETA solution space covers the cortical grey matter, sampled at 5 mm resolution, yielding a total of 6,239 voxels for which current density values are computed. The analysis was done separately for the statistically independent frequency bands (Kubicki et al. 1979; Niedermeyer and Lopes da Silva 2005) of delta (1.5–6 Hz), theta (6.5–8 Hz), alpha-1 (8.5–10 Hz), alpha-2 (10.5–12 Hz), beta-1 (12.5–18 Hz), beta-2 (18.5–21 Hz), and beta-3 (21.5–30 Hz); a gamma frequency band (35–44 Hz) was added.

sLORETA functional images were computed for each subject and condition separately in each of the eight frequency bands. The sLORETA functional images were frequency band-wise normalized (using the program option "time frame wise normalized"), that is, for each subject, the average of the power values over all sLORETA voxels was scaled to unity for each frequency band. Such scaling permits to exclusively detect differences in the spatial distribution of the activity between conditions across subjects while omitting the effects of irrelevant inter-individual differences in overall strength of the head-surface recorded voltages.

Brain electric activity differences between conditions were assessed using t statistics on the log-transformed sLORETA images. Correction for multiple testing after Nichols and Holmes

(2002) was applied. The sLORETA voxels are attributed to Brodmann areas (BA) based on their MNI coordinates.

The possible effects of elapsed time

The experimental protocol clearly involved a potential time effect in that the sequence of recording conditions was fixed, following the meditation routines of the participants; they habitually first did the initiating breath counting, then the meditation states of ‘‘Thinking of Nothing,’’ followed by ‘‘Qigong.’’ Theoretically desirable intermittent resting conditions were not acceptable to the meditators.

We tested the sLORETA tomography images of initial resting versus final resting for time effects: There were no significant differences (corrected for multiple testing) in any of the eight frequency bands. Therefore, the current density values were averaged across the two resting conditions for each subject as ‘‘mean rest.’’

2.1.4. Results

Differences between ‘‘Qigong’’ and ‘‘Thinking of Nothing’’

The strength of voxel activation differed at $p<0.05$ (after correction for multiple testing) between the meditation conditions ‘‘Thinking of Nothing’’ and ‘‘Qigong’’ only in the frequency bands of alpha-2 (critical $t>6.286$ for corrected $p<0.05$; best observed p(corrected) = 0.0074 was at $t = 7.966$) and beta-1 (critical $t>6.423$ for corrected $p<0.05$; best observed p(corrected) = 0.026 was at $t = -8.171$). These results are illustrated in the glass brain head views of Fig. 1. The other six frequency bands (delta, theta, alpha-1, beta-2, beta-3, and gamma) did not show significant differences after correction for multiple testing.

In the alpha-2 frequency band, all 125 voxels that differed significantly were more active in ‘‘Qigong’’ than in ‘‘Thinking of Nothing’’; they formed a single cluster in the parietal Brodmann areas 5 (N = 25), 7 (N = 84), 31 (N = 14), and 40 (N = 2), all in the right hemisphere (Fig. 1, upper row).

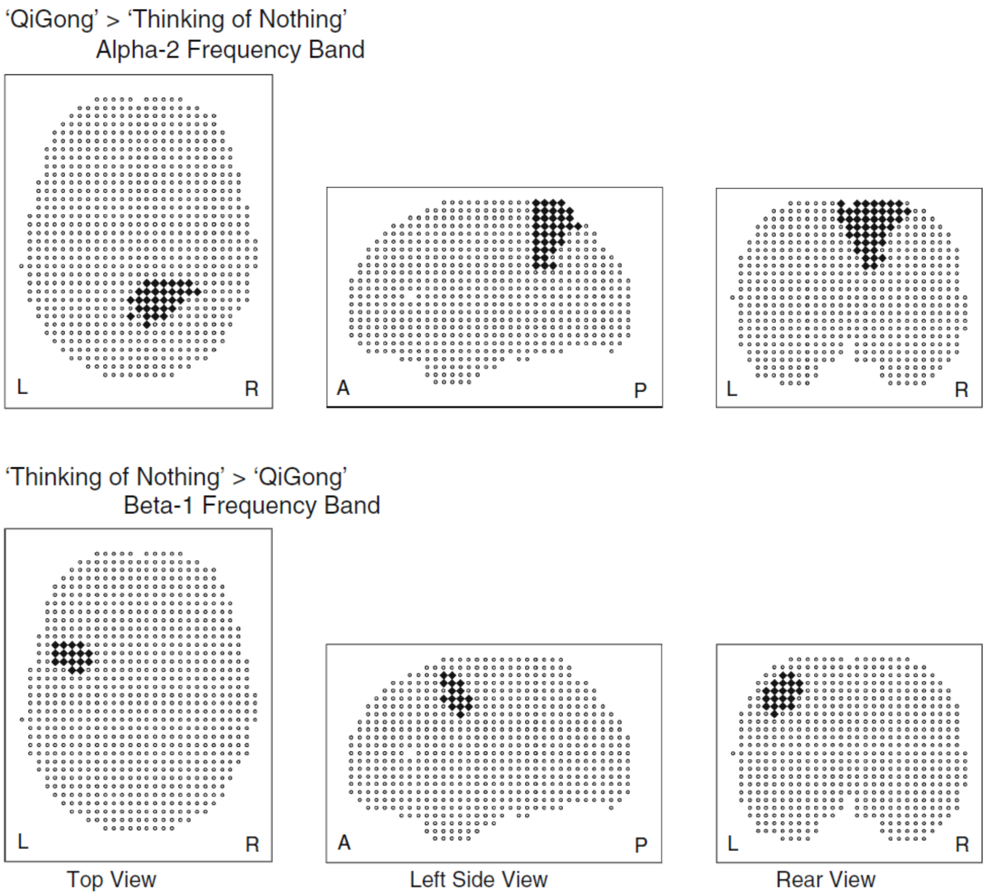

Fig. 1 Comparison of brain activity during "Qigong" and "Thinking of Nothing." Glass brain views, from left to right: axial, sagittal, and coronal views. Upper row: "Qigong" had stronger activity than "Thinking of Nothing" in the alpha-2 EEG frequency band (10.5–12 Hz). Lower row: "Thinking of Nothing" had stronger activity than "Qigong" in the beta-1 EEG frequency band (12.5–18 Hz). Dark voxels: Differences between the meditative states at $p<0.05$ after correction for multiple testing. Light voxels: sLORETA voxel space (MNI; left to right: -70 to +70 mm; posterior to anterior: -100 to +65 mm; inferior to superior: -45 to +70 mm)

There was no significant correlation (corrected for multiple testing) of alpha-2 voxel strength during "Qigong" (as well as during "Thinking of Nothing") with years of meditation experience or with age.

In the beta-1 frequency band, all 37 voxels that differed significantly were more active in "Thinking of Nothing" than in "Qigong"; they formed a single cluster in the frontal Brodmann areas 6 (N = 31), 8 (N = 3) and 9 (N = 3), all in the left hemisphere (Fig. 1, lower row).

As above for alpha-2, there was no significant correlation (corrected for multiple testing) of beta-1 voxel strength during "Qigong" (as well as during "Thinking of Nothing") with years of meditation experience or with age.

The general trend of the differences

The two EEG frequency bands of interest yielded significant differences between meditation conditions in different brain regions as reported above. Reducing the statistical thresholding showed that these different brain regions reported above represent a general trend in both frequency bands: At uncorrected values of $p<0.05$ ($df = 7$, $t>2.36$), "Qigong" showed stronger activity than "Thinking of Nothing" in large posterior areas consisting in the alpha-2 band of 1993 of all 6,239 LORETA voxels and in the beta-1 band of 1,067 of all 6,239 LORETA voxels (Fig. 2a), while "Thinking of Nothing" showed stronger activity than "Qigong" in large anterior areas consisting in the alpha-2 band of 2,513 of all 6,239 LORETA voxels and in the beta-1 band of 1,210 of all 6,239 LORETA voxels (Fig. 2d). In other words, about 2/3 of all voxels reached $p<0.05$ in the alpha-2 band, and about 1/3 of all voxels in the beta-1 band.

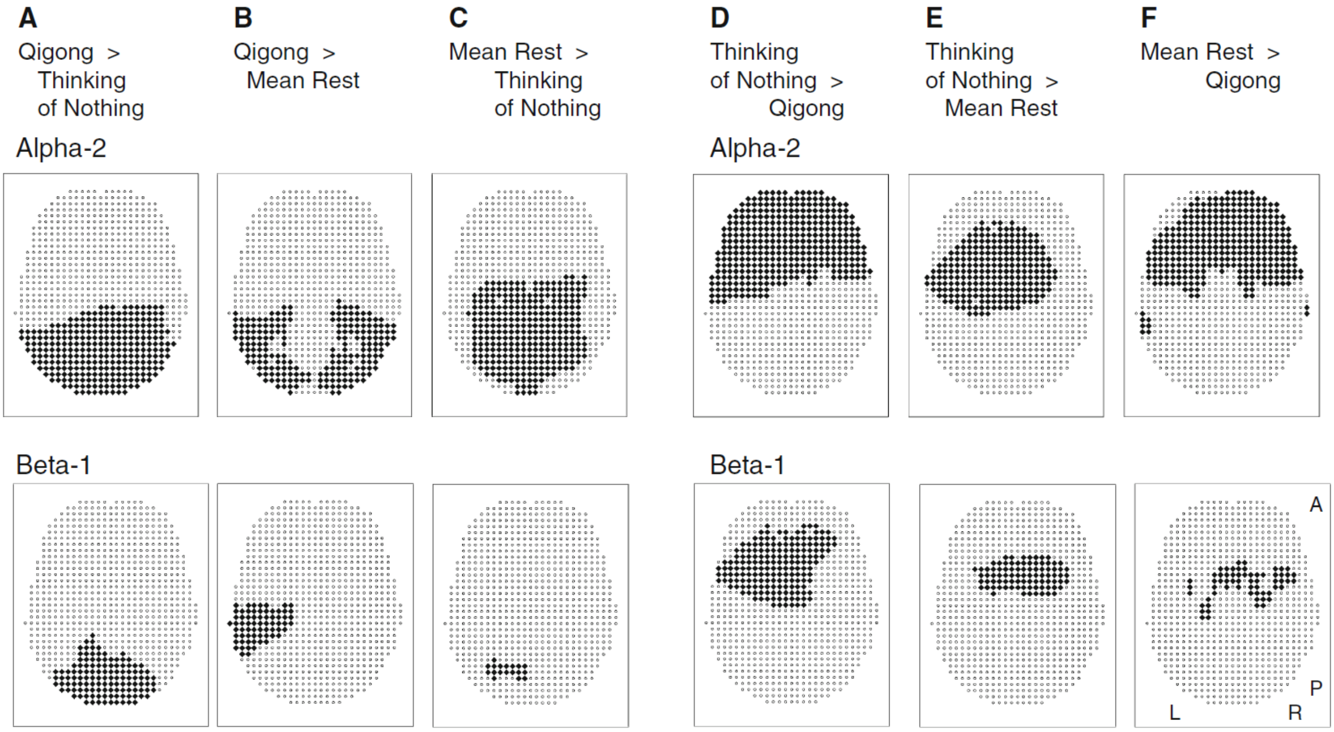

Fig. 2 Comparison of brain activity during the conditions "Qigong," "Thinking of Nothing," and no-task rest in the two EEG frequency bands (alpha-2 and beta-1) that showed significant differences between the two meditative states. Glass brain axial views. Dark voxels: Differences at p\0.05 (not corrected for multiple testing). Light voxels: sLORETA voxel space (MNI; left to right: -70 to +70 mm; posterior to anterior: -100 to +65 mm)

Differences between the two meditation states and no-task resting

To clarify how the brain regional activations in the two frequency bands of interest differed between the practitioners' resting state and the two meditation states, mean rest was tested against "Qigong" and against "Thinking of Nothing." There were no significant results after correction for multiple testing. However, at uncorrected $p<0.05$, in both frequency bands, "Qigong" differed from rest with stronger activity in more posterior regions compared to where "Thinking of Nothing" differed from rest (compare Fig. 2b to Fig. 2e, and Fig. 2c to Fig. 2f). In other words, for both frequency bands of interest, Fig. 2 shows that "Qigong" engaged posterior areas, while "Thinking of Nothing" engaged anterior areas.

The number of qualifying voxels involved in the differences was much higher in the alpha-2 band than in the beta-1 band as shown in Table 1. Further, Fig. 2 and Table 1 show that the general activity level of the no-task resting state was between the two meditation states, differing from either one, but in opposite directions.

Table 1. Numbers of voxels different at $p<0.05$ (uncorrected) illustrated in Fig. 2.

	A QG>TN	B QG>rest	C rest>TN	D TN>QG	E TN>rest	F rest>QG
A-2	1993	656	1215	2513	1754	967
B-1	1067	315	27	1210	141	227

Footnote: A-2: alpha-2 frequency; B-1: beta-1 frequency; QG: 'QiGong';
TN: 'Thinking of Nothing'; rest: mean rest. A-F: columns of Fig. 2.

2.1.5. Discussion

Intracerebral source imaging showed that the brain electric activity clearly differed between the two forms of meditation, the exercise of "Qigong" versus the exercise of "Thinking of Nothing" in the QiGong tradition, thus supporting hypothesis (1).

"Qigong" showed significantly stronger activity than "Thinking of Nothing" in the EEG alpha-2 frequency band in a single cluster of voxels in the right parietal lobe.

EEG alpha frequency activity reportedly increases during tasks not requiring attention to the environment, that is, during internally directed attention (Cooper et al. 2003; Palva and Palva 2007), specifically parietal alpha (Ray and Cole 1985). Increased alpha was observed in particular during working memory performance (Klimesch 1999; Jensen et al. 2002; Palva and Palva 2007; at the parietaloccipital junction: Tuladhar et al. 2007). Thus, the earlier interpretation of alpha generally representing "idling" has given way to the view that alpha indicates the suppression of visual input in order to free capacity for other processing (e.g., Tuladhar et al. 2007).

The right parietal significant cluster included voxels in BAs 5, 7, 31, and 40. Most voxels were in BAs 5 and 7 that constitute the secondary sensorimotor cortex; this cortex, however, also is involved in higher functions such as the perception of the personal space (Lloyd et al. 2006), attention (Jovicich et al. 2001; Luks and Simpson 2004; Caplan et al. 2006) as well as memory functions which were early on observed in these areas (personal space: Tulving et al. 1994; spatial memory: Constantinidis and Steinmetz 1996; intention coding: Snyder et al. 1997) and which are of pivotal importance for self-reference processes (see Kihlstrom et al. 2003; Conway 2005). Also, similar to BA 5 and BA 7, BA 31 activity has been associated with selfreferenced cognition (third versus first person perspective: Ruby and Decety 2004), in addition to evaluative judgments (Zysset et al. 2002). The range of functions ascribed to BA 40 include past-related information processing like recollection of previously experienced events (Tulving et al. 1994) and reestablishing executive control over previously automatized behavior (Kübler et al. 2006). In sum, embedded into the standard function of input integration in the parietal areas, self-referencing recollection and attentive control of earlier learned behavior experience is stronger in ‘‘Qigong’’ than in ‘‘Thinking of Nothing.’’

On the other hand, ‘‘Thinking of Nothing’’ showed significantly stronger activity than ‘‘Qigong’’ in the EEG beta-1 frequency band in a single cluster of voxels in the left frontal lobe.

EEG beta frequency activity generally indicates activation–excitation–facilitation (Lopes da Silva 1991) and increases during attention (Wrobel 2000; in particular beta- 1: Kisley and Cornwell 2006; Basile et al. 2010) as well as with alertness (Makeig and Inlow 1993; Lehmann et al. 1995) and during various mental activities, for example, during mental representation of objects (Tallon-Baudry and Bertrand 1999).

The significant left frontal cluster was located mostly in BA 6, with some voxels in the neighboring BAs 8 and 9. BA 6—although being a premotor or supplementary motor area—frequently is involved without motor activity in cognitive functions (imagery: Mellet et al. 1996; comparisons: Dehaene et al. 1996; numerical, verbal, and spatial tasks: Hanakawa et al. 2002; encoding-recognition: Ranganath et al. 2003; deductive reasoning: Reverberi et al. 2007). BAs 8 and 9 likewise are activated during higher functions such as executive control (Sarazin et al. 1998; Kübler et al. 2006), inductive reasoning (Goel et al.1997), and memory functions (Okuda et al. 2000; Ranganath et al. 2003; Babiloni et al. 2005). Thus, ‘‘Thinking of Nothing’’ was associated with cogitation and memories within the prefrontal areas which also supervise motor control processing. This may well reflect the recurring attempts to skip such mentations while pursuing the goal of the ‘‘Thinking of Nothing’’ meditation. We note that BAs 6, 8, and 9 were not parts of the left frontal core area of abstract thought reported earlier (Lehmann et al. 2010) and that they did not include the classical language areas BA 45 and 46, thereby making it unlikely that verbalizations of abstract concepts were involved.

Our hypothesis (2) that ‘‘Qigong’’ might involve prominent activity of frontal motor areas was not supported by the present results. The execution of the slow movements might have been so strongly automated that it needed only an undetectable engagement of central control.

We had formed hypothesis (3) that brain electric activity during ‘‘Qigong’’ might be an increase of what occurs during ‘‘Thinking of Nothing,’’ because the meditators said that it is necessary to do ‘‘Thinking of Nothing’’ before doing ‘‘Qigong.’’ But, hypothesis (3) was not supported by the results: The results for no-task rest were positioned between the two meditations. The differences within the two frequency bands between the two meditations at the reduced thresholding of p\0.05 clearly show (Fig. 2a, d) the stronger posterior activation during ‘‘Qigong’’ and the stronger anterior activation during ‘‘Thinking of Nothing,’’ neatly separated in space, and clearly reflected by corresponding differences from no-task rest: stronger posterior activation during ‘‘Qigong,’’ stronger anterior activation during ‘‘Thinking of Nothing’’ (Fig. 2b, e).

We appreciate that no-task rest in the meditators may not be quite the same as no-task rest in a control population since experienced meditators reportedly show persisting meditation effects in their brain electric activity at rest when they do not meditate (Tebecis 1975; Itoh et al. 1996; Newberg et al. 2001; Davidson et al. 2003; Lutz et al. 2004; Aftanas and Golosheykin 2005; Travis and Arenander 2006; Faber et al. 2008; Tei et al. 2009). At any case, no-task rest in our practitioners implies the absence of willfully intended meditation and therefore appears to be a valid meditation-neutral reference condition.

Meditation experience as well as age of our meditators did not correlate with the results. As reports of correlations between brain activity and meditation experience vary widely over studies and measures, our results will increase the knowledge base but are not surprising. For example, Berkovich-Ohana et al. (2012) in their EEG gamma band study observed no correlation with experience. Cahn et al. (2010) reported expertise-dependent increase in gamma band activity, but no effect on theta and beta. Murata et al. (1994) reported theta frequency waves increase with experience while alpha waves did not. Lutz et al. (2004) observed a significant correlation with experience in only one of six gamma band measures. Travis and Arenander (2006) reported increased alpha-1 coherence with experience. Interestingly, Brefczynski-Lewis et al. (2007) noted that the fMRI result dependence on experience shows an inverted U-shaped distribution, that is, that eventually, very much experience has minimal effects on results, and that many brain regions showed significant negative correlation with hours of practice.

The present study yielded significant increases during ‘‘Qigong’’ in two of the eight EEG frequency bands, in alpha-2 (posterior) and beta-1 (anterior), thereby partially agreeing with two of the eight QiGong EEG reports, that is, with the reported general increase in alpha-2 (Lee et al. 1997; Minegishi et al. 2009) and beta-1 power (Minegishi et al. 2009), but disagreeing with the other six QiGong reports (see introduction). Neither theta nor gamma frequencies were significant in the present study although they were often involved in reported EEG changes during meditation which, however, vary widely over analysis approaches and traditions. At first, reports of alpha dominated the field, but fast beta was also noted (e.g., Das and Gastaut 1957 in Yoga). Later, in addition to alpha and beta (including 40 Hz), theta occurrence was reported (e.g., in Zen: Kasamatsu and Hirai 1966; in Transcendental Meditation: Wallace et al. 1971; Banquet 1973; Hebert and Lehmann 1977; more recently, for example, in non-directive meditation: Lagopoulos et al. 2009 and in concentrative meditation: Baijal and Srinivasan 2010). It is noteworthy that of the 78 experienced meditators in Hebert and Lehmann (1977), only 21 showed the theta burst phenomenon. Lately, the gamma frequency band attracted particular attention during meditation (Lehmann et al. 2001; Lutz et al. 2004; Cahn et al. 2010; Lavallee et al. 2011; Berkovich-Ohana et al. 2012). In this literature, each study examined meditators from one tradition with a specific analysis approach; the results do not indicate clear EEG differences between meditation traditions. It appears that Cahn and Polich's (2006) statement that ‘‘differences among meditative practices have not been well established’’ still holds. In fact, we observed EEG changes that were common during meditation in five traditions (Lehman et al. 2012), that is, a generally reduced functional connectivity (intracerebral lagged EEG coherence) in all eight frequency bands, in support of Newberg and Iversen (2003) that ‘‘the end results of many practices of meditation are similar’’ (see also Fischer 1971; Davidson 1976).

The basic feature of our present results, the increase in posterior brain activation during ‘‘Qigong’’ versus ‘‘Thinking of Nothing’’, or no-task rest was also observed for optimal meditative states in other traditions (versus rest: Lou et al. 1999; Berkovich-Ohana et al. 2012; versus controls: Cahn et al. 2010; sidhi versus transcending: Travis 2011), contrary to other studies that reported increases in frontal activity (e.g., Davidson et al. 2003; Hölzel et al. 2007; Davanger et al. 2010; Engström and Söderfeldt 2010; Lagopoulos et al. 2009; Travis et al. 2010). The usual issues of different measurement and analysis methods, of sometimes fundamentally different concepts of result interpretation, and of different meditation techniques prevent binding conclusions.

In sum, our source imaging results show stronger activation of posterior right parietal areas during ‘‘Qigong’’ and of anterior left prefrontal areas during ‘‘Thinking of Nothing’’, reflecting a predominance of self-reference, attention- and input-centered information processing during the ‘‘Qigong’’ meditation and of control-centered information processing during the ‘‘Thinking of Nothing’’ meditation. One may speculate that the ‘‘Thinking of Nothing’’ exercise leads to such a strong degree of automation of attention to no-thinking that the participating processes become undetectable in the subsequent, new, and deeper meditation state of “Qigong” that the meditators claim to imply transcending.

The shortcoming of this EEG meditation study is that it did not include—as many other meditation studies—subjective ratings of the experienced quality of the meditations, and no reports of private thought contents during the meditations, and no assessment of the meditators’ personality parameters. Why are there so few systematic reports on subjective experience during meditation? For example, subjective responses in questionnaires filled out after a meditation study turned out to be impossible to quantitate or analyze (Newberg et al. 2001). One could suspect that (a) the unusual meditation experiences might be difficult to verbalize, that (b) they probably are distorted by habitual terminology because of their unfamiliar mystic character, that (c) they often are obviously disfigured by poetic embellishments or meditation tradition-specific standard terminology, and that (d) they might be too varied across individuals to easily show common characteristics. Subjective data (e.g., Hebert and Lehmann 1977; Piron 2003; Hölzel and Ott 2006; Aftanas and Golocheikine 2001; Travis 2001; Baijal and Srinivasan 2010; Wang et al. 2011; Hasenkamp et al. 2012), however, could be very useful for comparisons between studies, and for sorting out brain states of different cogitations and of depth or quality of meditation, thereby more exactly identifying the involved brain functions.

2.1.6. Acknowledgements

This work was supported in part by grant Nr. 44/06 from the Bial Foundation, S. Mamede do Coronado, Portugal. We thank Qigong Master Feng-San Lee for the possibility to contact the meditators of his group and Mitsumasa Kawakami for helpful comments to experimental settings.

2.1.7. References

Aftanas L, Golosheykin S (2005) Impact of regular meditation practice on EEG activity at rest and during evoked negative emotions. Int J Neurosci 115(6):893–909.

Aftanas LI, Golocheikine SA (2001) Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. Neurosci Lett 310(1):57-60.

Babiloni C, Ferretti A, Del Gratta C, Carducci F, Vecchio F, Romani GL, Rossini PM (2005) Human cortical responses during one-bit delayed-response tasks: an fMRI study. Brain Res Bull 65(5):383-390.

Baerentsen KB, Stødkilde-Jørgensen H, Sommerlund B, Hartmann T, Damsgaard-Madsen J, Fosnaes M, Green AC (2010) An investigation of brain processes supporting meditation. Cogn Process 11(1):57-84.

Baijal S, Srinivasan N (2010) Theta activity and meditative states: spectral changes during concentrative meditation. Cogn Process 11(1):31-38.

Banquet JP (1973) Spectral analysis of the EEG in meditation. Electroenceph Clin Neurophysiol

35(2):143-151.

Basile LF, Lozano MD, Alvarenga MY, Pereira JF, Machado S, Velasques B, Ribeiro P, Piedade R, Anghinah R, Knyazev G, Ramos RT (2010) Minor and unsystematic cortical topographic changes of attention correlates between modalities. PLoS One 5(12):e15022.

Benson H, Malhotra MS, Goldman RF, Jacobs GD, Hopkins PJ (1990) Three case reports of the metabolic and electroencephalographic changes during advanced Buddhist meditation techniques. Behav Med 16(2):90-95.

Berkovich-Ohana A, Glicksohn J, Goldstein A (2012) Mindfulness-induced changes in gamma band activity – Implications for the default mode network, self-reference and attention. Clin Neurophysiol 123(4):700-710.

Brefczynski-Lewis JA, Lutz A, Schaefer HS, Levinson DB, Davidson RJ (2007) Neural correlates of attentional expertise in long-term meditation practitioners. Proc Natl Acad Sci USA 104(27):11483-11488.

Cahn BR, Polich J (2006) Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychol Bull 132(2):180-211.

Cahn BR, Delorme A, Polich J (2010) Occipital gamma activation during Vipassana meditation. Cogn Process 11(1):39-56.

Caplan JB, Luks TL, Simpson GV, Glaholt M, McIntosh AR. (2006) Parallel networks operating across attentional deployment and motion processing: a multi-seed partial least squares fMRI study. Neuroimage 29(4):1192-1202.

Chan AS, Cheung MC, Sze SL, Leung WW, Shi D (2011) Shaolin dan tian breathing fosters relaxed and attentive mind: a randomized controlled neuro-electrophysiological study. Evid-Based Compl Altern Med 2011:180704 (11 pages).

Constantinidis C, Steinmetz M (1996) Neuronal activity in posterior parietal area 7a during the delay periods of a spatial memory task, J Neurophysiol 76:1352–1355.

Conway MA (2005) Memory and the self. J Memory Language 53(4):594–628.

Cooper NR, Croft RJ, Dominey SJJ, Burgess AP, and Gruzelier J H (2003) Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. Int J Psychophysiol 47:65-74.

Das NN, Gastaut H (1957) Variation de l'activité électrique du cerveau, du coeur et des muscles squelettiques au cours de la méditation et de l'extase yogique. Electroenceph Clin Neurophysiol (Suppl 6): 211–219.

Davanger S, Ellingsen O, Holen A, Hugdahl K (2010) Meditation-specific prefrontal cortical activation during acem meditation: an fMRI study. Percept Mot Skills 111(1):291-306.

Davidson JM (1976) The physiology of meditation and mystical states of consciousness. Perspect Biol Med 19(3):345-379.

Davidson RJ, Goleman DJ (1977) The role of attention in meditation and hypnosis: A psychobiological perspective on transformations of consciousness. Int J Clin Exp Hyp 25:291–308.

Davidson RJ, Kabat-Zinn J, Schumacher J, Rosenkranz M, Muller D, Santorelli SF, Urbanowski F, Harrington A, Bonus K, Sheridan JF (2003) Alterations in brain and immune function produced by mindfulness meditation. Psychosom Med 65(4):564-570.

Dehaene S, Tzourio N, Frak V, Raynaud L, Cohen L, Mehler J, Mazoyer B (1996) Cerebral activations during number multiplication and comparison: a PET study. Neuropsychologia 34:1097–1106.

Dierks T, Jelic V, Pascual-Marqui RD, Wahlund LO, Julin P, Linden DEJ, Maurer K, Winblad B, Nordberg A (2000) Spatial pattern of cerebral glucose metabolism (PET) correlates with localization of intracerebral EEG-generators in Alzheimer's disease. Clin Neurophysiol 111:1817-1824.

Dietrich A (2003) Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. Conscious Cogn 12(2):231-256.

Dunn BR, Hartigan JA, Mikulas WL (1999) Concentration and mindfulness meditations: unique forms of consciousness? Appl Psychophys Biof 24(3):147-165.

Engström M, Söderfeldt B (2010) Brain activation during compassion meditation: a case study. J Altern Complem Med 16(5):597-599.

Faber PL, Steiner ME, Lehmann D, Pascual-Marqui RD, Jäncke L, Esslen M, Gianotti LRR (2008) Deactivation of the medial prefrontal cortex in experienced Zen meditators. Brain Topogr 20:172.

Fischer R (1971) A cartography of the ecstatic and meditative states. Science 174(4012):897-904.

Gellhorn E, Kiely WF (1972) Mystical states of consciousness: neurophysiological and clinical aspects. J Nerv Ment Dis 154(6):399-405.

Goel V, Gold B, Kapur S, Houle S (1997) The seats of reason? An imaging study of deductive and inductive reasoning. Neuroreport 8(5):1305-10.

Hanakawa T, Honda M, Sawamoto N, Okada T, Yonekura Y, Fukuyama H, and Shibasaki H (2002) The role of rostral Brodmann area 6 in mental-operation tasks: an integrative neuroimaging approach. Cerebral Cortex 12(11):1157-1170.

Hasenkamp W, Wilson-Mendenhall CD, Duncan E, Barsalou LW (2012) Mind wandering and attention during focused meditation: a fine-grained temporal analysis of fluctuating cognitive states. Neuroimage 59(1):750-760.

Hebert R, Lehmann D (1977) Theta bursts: an EEG pattern in normal subjects practicing the transcendental meditation technique. Electroenceph Clin Neurophysiol 42(3):397-405.

Hölzel B, Ott U (2006) Relationships between meditation depth, absorption, meditation practice, and mindfulness: A latent variable approach. Journal of Transpersonal Psychology 38(2):179-199.

Hölzel BK, Ott U, Hempel H, Hackl A, Wolf K, Stark R, Vaitl D (2007) Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. Neurosci Lett 421(1):16-21.

Itoh M, Miyazaki H, Takahashi Y (1996) Imaging of mind using positron emission tomography. J Intl Soc Life Info Sci 14(1):76-80.

Jasper HH (1958) The ten-twenty electrode system of the International Federation. Electroenceph Clin Neurophysiol 10:371-375.

Jensen O, Gelfand J, Kounios J, Lisman JE (2002) Oscillations in the alpha band (9–12 Hz) increase with memory load during retention in a short-term memory task. Cereb Cortex 12(8):877-882.

Jha AP, Krompinger J, Baime MJ (2007) Mindfulness training modifies subsystems of attention. Cogn Affect Behav Neurosci 7(2):109-119.

Jovicich J, Peters RL, Koch C, Braun J, Chang L, Ernst T (2001) Brain areas specific for attentional load in a motion-tracking task. J Cogn Neurosci 13(8):1048-1058.

Kabat-Zinn J (1982) An outpatient program in behavioral medicine for chronic pain patients based on the practice of mindfulness meditation: theoretical considerations and preliminary results. Gen Hosp Psychiatry 4(1):33-47.

Kasamatsu A, Hirai T (1966) An electroencephalographic study on the Zen meditation (Zazen). Folia Psychiatrica et Neurologica Japonica 20 :315–336.

Kihlstrom JF, Beer JS, Klein SB (2003) Self and identity as memory. In Leary MR, TangneyJ (eds) Handbook of Self and Identity. Guilford Press, New York, pp 68-90.

Kisley MA, Cornwell ZM (2006) Gamma and beta neural activity evoked during a sensory gating paradigm: Effects of auditory, somatosensory and cross-modal stimulation. Clin Neurophysiol 117(11):2549–2563.

Klimesch W (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev 29(2-3):169-195.

Kubicki S, Herrmann WM, Fichte K, Freund G (1979) Reflections on the topics: EEG frequency bands and regulation of vigilance. Pharmacopsychiatry 12:237-245.

Kübler A, Dixon V, Garavan H (2006) Automaticity and reestablishment of executive control-an fMRI study. J Cogn Neurosci 18(8):1331-1342.

Lagopoulos J, Xu J, Rasmussen I, Vik A, Malhi GS, Eliassen CF, Arntsen IE, Saether JG, Hollup S, Holen A, Davanger S, Ellingsen Ø (2009) Increased theta and alpha EEG activity during nondirective meditation. J Altern Complement Med 15(11):1187-1192.

Lavallee CF, Hunter MD, Persinger MA (2011) Intracerebral source generators characterizing concentrative meditation. Cogn Process 12(2):141-150.

Lee, M. S., Bae, B. H., Ryu, H., Sohn, J. H., Kim, S. Y., Chung, H. T. (1997) Changes in alpha wave and state anxiety during Chun Do Sun Bup Qi-training in trainees with open eyes. Am J Chinese Med 25:289–299.

Lehmann D, Faber PL, Achermann P, Jeanmonod D, Gianotti LRR, Pizzagalli D (2001) Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. Psychiatry Res Neuroimaging 108(2):111-121.

Lehmann D, Faber PL, Tei S, Pascual-Marqui RD, Milz P, Kochi K (2012) Reduced functional connectivity between cortical sources in five meditation traditions detected with lagged coherence using EEG tomography. Neuroimage 60:1574-1586.

Lehmann D, Grass P, Meier B (1995) Spontaneous conscious covert cognition states and brain electric spectral states in canonical correlations. Int J Psychophysiol 19(1):41-52.

Lehmann D, Pascual-Marqui RD, Strik WK, Koenig T (2010) Core networks for visual-concrete and abstract thought content: a brain electric microstate analysis. Neuroimage 49(1):1073-1079.

Lloyd D, Morrison I, Roberts N (2006) Role for human posterior parietal cortex in visual processing of aversive objects in peripersonal space. J Neurophysiol 95(1):205-214.

Lopes da Silva F. (1991) Neural mechanisms underlying brain waves: from neural membranes to networks. Electroenceph Clin Neurophysiol 79(2):81-93.

Lou HC, Kjaer TW, Friberg L, Wildschiodtz G, Holm S, Nowak M (1999) A 15O-H2O PET study of meditation and the resting state of normal consciousness. Hum Brain Mapp 7(2):98-105.

Luks TL, Simpson GV (2004) Preparatory deployment of attention to motion activates higher order motion-processing brain regions. Neuroimage 22:1515-1522.

Lutz A, Greischar LL, Rawlings NB, Ricard M, Davidson RJ (2004) Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. Proc Natl Acad Sci USA 101(46):16369–16373.

Lutz A, Slagter HA, Dunne JD, Davidson RJ (2008) Attention regulation and monitoring in meditation. Trends Cogn Sci 12:163-169.

Makeig S, Inlow M (1993) Lapses in alertness: coherence of fluctuations in performance and EEG spectrum. Electroenceph Clin Neurophysiol 86(1):23-35.

Mellet E, Tzourio N, Crivello F, Joliot M, Denis M, Mazoyer B (1996) Functional anatomy of spatial imagery generated from verbal instructions. J Neurosci 16:6504–6512.

Mikulas WL (1990); Mikulas, WL (1990) Mindfulness, self-control, and personal growth. In: Kwee, M.G.T. (Ed.), Psychotherapy, Meditation, and Health. East West Publications, London, pp. 151 164.

Minegishi Y, Isotani T, Yoshimura M, Yamada K, Nishida K, Morita S, Saito Y, Irisawa S, Ichikawa M, Kinoshita T, Kihara H. (2009) Spatial brain electric activity changes after Kakurin-qigong. In Kobayashi T, Ozaki I, Nagata K (eds) Brain Topography and Multimodal Imaging. Kyoto University Press, Kyoto, pp 107-108.

Mulert C, Jäger L, Schmitt R, Bussfeld P, Pogarell O, Möller HJ, Juckel G, Hegerl U (2004) Integration of fMRI and simultaneous EEG: towards a comprehensive understanding of localization and time-course of brain activity in target detection. Neuroimage 22:83-94.

Murata T, Koshino Y, Omori M, Murata I, Nishio M, Sakamoto K, Horie T, Isaki K

(1994) Quantitative EEG Study on Zen Meditation (Zazen). Jpn J Psychiat Neurol 48(4):881 890.

Newberg A, Alavi A, Baime M, Pourdehnad M, Santanna J, d'Aquili E (2001) The measurement of regional cerebral blood flow during the complex cognitive task of meditation: a preliminary SPECT study. Psychiatry Res 106(2):113–122.

Newberg AB, Iversen J (2003) The neural basis of the complex mental task of meditation: neurotransmitter and neurochemical considerations. Medical Hypotheses 61(2):282–291.

Nichols TE, Holmes AP (2002) Nonparametric permutation tests for functional neuroimaging: A primer with examples. Hum Brain Mapp 15:1-25.

Niedermeyer E, Lopes da Silva F (2005) Electroencephalography: Basic principles, clinical applications, and related fields, 5th edn. Lippincott Williams Wilkins, Philadelphia.

Okuda J, Fujii T, Yamadori A, Kawashima R, Tsukiura T, Ohtake H, Fukatsu R, Suzuki K, Itoh M, Fukuda H (2000) Retention of words in long-term memory: a functional neuroanatomical study with PET. Neuroreport 11(2):323-328.

Palva S, Palva JM (2007) New vistas for alpha-frequency band oscillations. Trends Neurosci 30(4):150-158.

Pan W, Zhang L, Xia Y (1994) The difference in EEG theta waves between concentrative and non-concentrative Qigong states – A power spectrum and topographic mapping study. J Trad Chin Med 14(3):212-218.

Pascual-Marqui RD (2002) Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. Methods Find Exp Clin Pharmacol 24 Suppl D:5-12.

Pascual-Marqui RD, Esslen M, Kochi K, Lehmann D (2002) Functional imaging with low-resolution brain electromagnetic tomography (LORETA): a review. Method Find Exp Clin Pharmacol 24 Suppl C:91-95.

Pascual-Marqui RD, Lehmann D, Koenig T, Kochi K, Merlo MC, Hell D, Koukkou M (1999) Low resolution brain electromagnetic tomography (LORETA) functional imaging in acute, neuroleptic-naive, first-episode, productive schizophrenia. Psychiatry Res 90(3):169-179.

Pascual-Marqui RD, Michel CM, Lehmann D (1994) Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. Int J Psychophysiol 18(1):49-65.

Peng CK, Henry IC, Mietus JE, Hausdorff JM, Khalsa G, Benson H, Goldberger AL (2004) Heart rate dynamics during three forms of meditation. Int J Cardiol 95(1):19-27.

Perlman DM, Salomons TV, Davidson RJ, Lutz A (2010) Differential effects on pain intensity and unpleasantness of two meditation practices. Emotion 10(1):65-71.

Piron H (2003) Meditation Depth, Mental Health, and Personal Development. Journal for Meditation and Meditation Research 3:45-58.

Qin Z, Jin Y, Lin S, Hermanowicz NS (2009) A forty-five year follow-up EEG study of Qigong practice. Int J Neurosci 119(4):538-552.

Raffone A, Srinivasan N (2010) The exploration of meditation in the neuroscience of attention and consciousness. Cogn Process 11(1):1-7.

Ranganath C, Johnson MK, D'Esposito M (2003) Prefrontal activity associated with working memory and episodic long-term memory. Neuropsychologia 41(3):378-389.

Ray WJ, Cole HW (1985) EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. Science 228:750–752.

Reverberi C, Cherubini P, Rapisarda A, Rigamonti E, Caltagirone C, Frackowiak RS, Macaluso E, Paulesu E (2007) Neural basis of generation of conclusions in elementary deduction. Neuroimage 38(4):752-762.

Ruby P, Decety J (2004) How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. J Cogn Neurosci 16(6):988-999.

Sarazin M, Pillon B, Giannakopoulos P, Rancurel G, Samson Y, Dubois B (1998) Clinicometabolic dissociation of cognitive functions and social behavior in frontal lobe lesions. Neurology 51(1):142-148.

Snyder LH, Batista AP, Andersen RA (1997) Coding of intention in the posterior parietal cortex. Nature 386:167-170.

Sun F, Wang J, Liu G, Jiao X, Zhang Z, Shi Y, Zhang T (1984) An analysis on EEG power spectrum and coherence during quiet state in QiGong. Acta Psychologica Sinica 17(4):76-81.

Tallon-Baudry C, Bertrand O (1999) Oscillatory gamma activity in humans and its role in object representation. Trends Cogn Sci 3(4):151-162.

Tart CT (1969) Altered States of Consciousness. New York: Wiley.

Tebecis AK (1975) A controlled study of the EEG during transcendental meditation: comparison with hypnosis. Folia Psychiatr Neurol Jpn 29(4):305–313.

Tei S, Faber PL, Lehmann D, Tsujiuchi T, Kumano H, Pascual-Marqui RD, Gianotti LR, Kochi K (2009) Meditators and non-meditators: EEG source imaging during resting. Brain Topogr 22(3):158-165.

Travis F (2001) Autonomic and EEG patterns distinguish transcending from other experiences during Transcendental Meditation practice. Int J Psychophysiol 42:1-9.

Travis F (2011) Comparison of coherence, amplitude, and eLORETA patterns during Transcendental Meditation and TM-Sidhi practice. Int J Psychophysiol 81(3):198-202.

Travis F, Arenander A (2006) Cross-sectional and longitudinal study of effects of transcendental meditation practice on interhemispheric frontal asymmetry and frontal coherence. Int J Neurosci 116(12):1519-1538.

Travis F, Haaga DA, Hagelin J, Tanner M, Arenander A, Nidich S, Gaylord-King C, Grosswald S, Rainforth M, Schneider RH (2010) A self-referential default brain state: patterns of coherence, power, and eLORETA sources during eyes-closed rest and Transcendental Meditation practice. Cogn Process 11(1):21-30.

Travis F, Shear J (2010) Focused attention, open monitoring and automatic selftranscending: Categories to organize meditations from Vedic, Buddhist and Chinese traditions. Conscious Cogn 19:1110-1118.

Tuladhar AM, ter Huurne N, Schoffelen JM, Maris E, Oostenveld R, Jensen O (2007) Parieto-occipital sources account for the increase in alpha activity with working memory load. Hum Brain Mapp 28:785–792.

Tulving E, Kapur S, Markowitsch HJ, Craik FI, Habib R, Houle S (1994) Neuroanatomical correlates of retrieval in episodic memory: auditory sentence recognition. Proc Natl Acad Sci USA 91(6):2012-2015.

Vaitl D, Birbaumer N, Gruzelier J, Jamieson G, Kotchoubey B, Kübler A, Lehmann D, Miltner WHR, Ott U, Pütz P, Sammer G, Strauch I, Strehl U, Wackermann J, Weiss T (ASC Consortium) (2005) Psychobiology of altered states of consciousness. Psychol Bull 131(1): 98 127.

Vitacco D, Brandeis D, Pascual-Marqui R, Martin E (2002) Correspondence of event-related potential tomography and functional magnetic resonance imaging during language processing. Hum Brain Mapp 17:4-12.

Wallace RK, Benson H, Wilson AF (1971) A wakeful hypometabolic physiologic state. Am J Physiol 221(3):795-799.

Wang DJ, Rao H, Korczykowski M, Wintering N, Pluta J, Khalsa DS, Newberg AB (2011) Cerebral blood flow changes associated with different meditation practices and perceived depth of meditation. Psychiatry Res 191(1):60-67.

Worrell GA, Lagerlund TD, Sharbrough FW, Brinkmann BH, Busacker NE, Cicora KM, O'Brien TJ (2000) Localization of the epileptic focus by Low-Resolution Electromagnetic Tomography in patients with a lesion demonstrated by MRI. Brain Topogr 12:273-282.

Wrobel A. (2000) Beta activity: a carrier for visual attention. Acta Neurobiol Exp (Warsz) 60(2):247-260.

Yang L, Wilke C, Brinkmann B, Worrell GA, He B (2011) Dynamic imaging of ictal oscillations using non-invasive high-resolution EEG. Neuroimage 56(4):1908-1917.

Yang SH, Yang QF, Shi JM. (1994) [Observation of electroencephalogram spectrum changes over one year of Qigong training]. [Article in Chinese, Abstract in English] Zhongguo Zhong Xi Yi Jie He Za Zhi 14(11):643-646.

Yuasa Y (1990) Ki to ningen kagaku: Nitchu shinpojumu koenshu (Qi and human science; in Japanese). Hiraga Publishing, Tokyo, 361 pp.

Zeidan F, Johnson SK, Gordon NS, Goolkasian P (2010) Effects of brief and sham mindfulness meditation on mood and cardiovascular variables. J Altern Complement Med 16:867 873.

Zhang J-Z, Zhao J, He Q-N (1988) EEG findings during special psychical state (Qi Gong state) by means of compressed spectral array and topographic mapping Comput Biol Med 18(6):455–463.

Zumsteg D, Friedman A, Wieser HG, Wennberg RA (2006a) Propagation of interictal discharges in temporal lobe epilepsy: correlation of spatiotemporal mapping with intracranial foramen ovale electrode recordings. Clin Neurophysiol 117:2615-2626.

Zumsteg D, Lozano AM, Wennberg RA (2006b) Depth electrode recorded cerebral responses with deep brain stimulation of the anterior thalamus for epilepsy. Clin Neurophysiol 117:1602-1609.

Zumsteg D, Wennberg RA, Treyer V, Buck A, Wieser HG (2005) H2(15)O or 13NH3 PET and electromagnetic tomography (LORETA) during partial status epilepticus. Neurology 65:1657-1660.

Zysset S, Huber O, Ferstl E, von Cramon DY (2002) The anterior frontomedian cortex and evaluative judgment: an fMRI study. Neuroimage 15(4):983-991.

2.2. Study II- Zazen Meditation versus No-Task Resting: sLORETA Intracerebral Source Localization[2]

2.2.1. Abstract

Meditation is a self-induced and willfully initiated practice that alters the state of consciousness. The meditation practice of Zazen, like many other meditation practices, aims at disregarding intrusive thoughts while controlling body posture. It is an open monitoring meditation characterized by detached moment-to-moment awareness and reduced conceptual thinking and self-reference. Which brain areas differ in electric activity during Zazen compared to task-free resting? Since scalp electroencephalography (EEG) waveforms are reference-dependent, conclusions about the localization of active brain areas are ambiguous. Computing intracerebral source models from the scalp EEG data solves this problem. In the present study we applied source modeling using low resolution brain electromagnetic tomography (LORETA) to 58-channel scalp EEG data recorded from 15 experienced Zen meditators during Zazen and no-task resting. Zazen compared to no-task resting showed increased alpha-1 and alpha-2 frequency activity in an exclusively right-lateralized cluster extending from prefrontal areas including the insula to parts of the somatosensory and motor cortices and temporal areas. Zazen also showed decreased alpha and beta-2 activity in the left angular gyrus and decreased beta-1 and beta-2 activity in a large bilateral posterior cluster comprising the visual cortex, the posterior cingulate cortex and the parietal cortex. The results include parts of the default mode network and suggest enhanced automatic memory and emotion processing, reduced conceptual thinking and self-reference on a less judgmental, i.e., more detached moment-to-moment basis during Zazen compared to no-task resting.

2.2.2. Introduction

Meditation is a volitionally self-induced practice that alters the state of consciousness. Many different practices exist. They usually involve the regulation of attention, awareness and emotion (Raffone and Srinivasan 2010; Shapiro and Walsh 2003). Attempts have been made to classify the many different meditation practices into useful categories. Based on their focus of attention, meditation practices have been classified as either *focused attention* or *open monitoring* practices (Dunn et al. 1999; Lutz et al. 2008; Raffone and Srinivasan 2010). The former put the focus of

---

[2] This study has been published: Faber, P.L., Lehmann, D., Gianotti, L.R., Milz, P., Pascual-Marqui, R.D., Held, M. & Kochi, K. (2014) Zazen meditation and no-task resting EEG compared with LORETA intracortical source localization. Cognitive Processing **16**(1), 87-96.

attention on one chosen object, whereas the latter train an effortless, open and nonjudgmental awareness in the present moment.

Where does the Zen-Buddhism practice of Zazen fit in? In many meditation practices, specific instructions are given such as attending to or counting one's breath, or continually repeating a visual or auditory mantra, or doing repetitive limb or body movements, or assuming certain body positions. The classical instruction for the practice of Zazen is "sitting fixedly, think of not thinking. How do you think of not thinking? Nonthinking. This is the art of Zazen" (Zazen gi: Dogen 1243/2001). Zazen, like other meditation practices, aims at disregarding any intrusive thoughts (Cahn and Polich 2006) arising from memory or outside sources. It favors the detached mindful perception of the ongoing moment-to-moment experience (Austin 2013), which leads to a calm awareness that in turn allows for the emergence of undisturbed introspective memory processes (Austin 2011). Zazen belongs to those meditation practices that have been described as means to recognize the nature of emotional and cognitive patterns (Lutz et al. 2008; Raffone and Srinivasan 2010). It is also characterized by reduced conceptual processing and self-reference (Pagnoni et al. 2008). Based on these descriptions and the obvious emphasis on aspects of open monitoring, Zazen can be considered a typical open monitoring practice.

Zazen is subjectively different from simple non-meditative no-task resting. While the task-free resting state is characterized by mind wandering, Zazen is characterized by reduced conceptual thinking and self-reference, momentary awareness and the active upholding (executive control) of detachment from spontaneous mentation and perceptions. Also, Zazen requires continual control of the sitting posture. The question arises: Given that higher brain functions are incorporated by networks of activated local brain areas (Britz et al. 2010; Laufs et al. 2003; Mesulam 1990), what is the localization of the brain areas whose activity differs between the state of consciousness reached during Zazen and the state of consciousness during non-meditative no-task resting? Open monitoring in general can be expected to engage brain areas implicated in monitoring, vigilance and the disengagement of attention from distracting perceptions, and brain areas implicated in interoception as well as in the regulation of emotional processes (Lutz et al. 2008). A side issue is whether meditation experience affects the activity of these brain areas during Zazen and resting.

The “default mode of brain function” (Raichle et al. 2001) describes a resting state network more active during waking rest than during specific goal-directed behaviors. This default mode network (DMN) consists of regions in the medial prefrontal cortex, the posterior cingulate cortex (PCC) and precuneus, the angular gyrus and the left superior and middle frontal gyri, hippocampus and parahippocampus (Buckner et al. 2008; Gusnard et al. 2001; Raichle et al.

2001). The brain areas constituting the DMN are of special interest for the study of meditation as their activity has been linked to mind wandering (Mason et al. 2007), episodic memories (Buckner et al. 2008; Greicius et al. 2004) and conceptual processing (Binder et al. 1999), all important for maintaining the sense of self (Gusnard et al. 2001; Lou et al. 2004). As all these processes are affected by meditation, the DMN brain regions are key areas where brain electric differences between Zazen and no-task resting would be expected.

When assessing brain activity, electroencephalography (EEG) recommends itself over other techniques (e.g., fMRI, PET and NIRS), because the very high time resolution of EEG makes it possible to distinguish inhibiting from facilitating brain activity. With increasing wave frequency, the functional significance of EEG waveshapes changes from inhibition to routine functioning to facilitation (Makeig and Jung 1995; Niedermeyer and Lopes da Silva 2005; O'Gorman et al. 2013).

Several studies reported EEG findings concerning Zazen meditation compared to resting (Becker and Shapiro 1981; Kasamatsu and Hirai 1966; Murata et al. 1994) and concerning other Zen meditations practicing attention to breathing (Huang and Lo 2009; Kubota et al. 2001; Takahashi et al. 2005; Yu et al. 2011). Most of these studies found an increase of alpha and theta EEG frequency activity during meditation. All of these studies analyzed scalp recorded EEG waveshapes and therefore conclusions about activations of brain areas derived from these analyses are problematic.

Localization of brain activity based on scalp EEG waveshape analysis has been criticized because the recorded EEG waveshapes depend on the chosen recording reference (there is no zero reference, Geselowitz 1998). As a solution, the computation of intracerebral source models from scalp EEG data has been proposed (Ruchkin 2005).

EEG-based source modeling has been applied to meditation data in several studies. During concentration meditation, compared to resting increased beta frequency activity and decreased gamma activity was reported (Lavallee et al. 2011). During transcendental meditation, increased alpha frequency activity and decreased beta activity was observed (Travis et al. 2010; Yamamoto et al. 2006).

To our knowledge, the present study is the first to use source modeling to analyze multichannel EEG data to localize the active brain areas during Zazen and no-task resting. We use a well-validated method that implements source model computation of scalp EEG data: low resolution brain electromagnetic tomography (LORETA; Pascual-Marqui et al. 1994, 1999).

We hypothesized that Zazen and resting will activate different brain areas. Based on the above reviewed modulation of processes concerning memory, emotion, conceptual thinking, self-reference and detached momentary awareness during Zazen, we specifically hypothesized that source localization differences between the Zazen meditation state and the no-task resting state comprise brain areas that are part of the DMN: the PCC, precuneus, angular gyrus, hippocampus and parahippocampus. We expected these areas to show decreased facilitatory activity during Zazen. We also expected brain areas involved in monitoring body posture (sensory and motor areas) to show increased facilitatory activity during Zazen.

2.2.3. Materials and methods

Participants

Experienced meditators were recruited at a local Soto Zen meditation center in Zurich (Zen Dojo Zürich, http://www.zen.ch). Multichannel EEG was recorded from 15 meditators (9 males). Their mean age was 42 years (SD 7.9; range 29-56). Their mean experience in Zen meditation was 12.3 years (SD 5.6; range 5-21). Each participant received CHF 40 as financial compensation. All participants were right-handers. All reported no previous or current psychiatric diagnosis, head trauma or drug usage, and none used any centrally active medication. After complete information about the study design, all participants gave their written consent. The study was approved by the local Ethics Committee and thus conforms to the ethical standards of the 1964 Declaration of Helsinki.

Recording conditions

The EEG was recorded during the following conditions:

(1) Initial resting: The participants were sitting comfortably in a chair with arm- and backrest. Duration: 4 min (20 s eyes open, 40 s eyes closed, repeated four times). This design was used to avoid that participants became sleepy during this resting condition. Only the eyes closed data were used for analysis.

(2) Zazen: The participants were sitting on a meditation cushion (zafu) in a full or part Lotus position with their hands held together in front of the navel. They sat about 1 m from the unstructured, gray wall of the dimly lit recording chamber with their eyes two-thirds closed. Duration: 60 min.

(3) Final resting: same as condition (1) initial resting.

EEG recording and questionnaires

The EEGs were recorded at the University Hospital of Psychiatry, Zurich, in a sound and electrically shielded EEG chamber. 58 electrodes were placed on the scalp with an "Easy Cap"

(Easycap, Herrsching-Breitbrunn, Germany) using the following locations according to the International 10-10 system (Nuwer et al. 1998): Fp1/2, AF7/8, AF3/4, AFz, F7/8, F5/6, F3/4, F1/2, Fz, FT7/8, FC5/6, FC3/4, FCz, T7/8, C5/6, C3/4, C1/2, Cz (reference), TP7/8, CP5/6, CP3/4, CP1/2, CPz, P7/8, P5/6, P3/4, P1/2, Pz, PO7/8, PO3/4, POz, O1/2, Oz. Horizontal and vertical eye movements were recorded with electrodes at the left and right outer canthi and left infraorbital. Impedances were kept below 5 kΩ. The signals were amplified, band passed from 0.5 to 100 Hz and digitized at 250 samples/s using a 64-channel EEG/ERP system (M&I Ltd., Prague, Czech Republic).

During the application of the electrodes, the participants filled out three questionnaires. One questionnaire asked about past head traumata, psychiatric illnesses, drug abuse and medication and asked for gender, age, education and Zen meditation experience. A questionnaire (Chapman and Chapman 1987) determined the handedness; all participants were right-handed (mean score = 13.6, SD = 1.02).

Data conditioning

Off-line, the EEG data were carefully reviewed using the BrainVision Analyzer software (Brain Products, Munich, Germany). Eye-movement artifacts were corrected using independent component analysis. EEG data containing muscle, movement and/or technical artifacts were marked; noisy channels were linearly interpolated. All artifact-free data were parsed into 2 s epochs for analysis. On average, 119 seconds (SD = 18.1) of EEG data were available per participant for the initial resting condition, 114 seconds (SD = 32.8) for final resting condition and 1632 s = 27.2 min (SD = 692 s = 11.5 min) for the Zazen condition.

Data analysis

Intracortical functional source localization

The 58-channel EEG data were analyzed using the sLORETA software version (standardized low resolution brain electromagnetic tomography, Pascual-Marqui 2002; free academic software available at http://www.uzh.ch/keyinst/loreta.htm) of the LORETA functional tomography analysis approach (Pascual-Marqui et al. 1994, 1999). sLORETA is a properly standardized discrete, linear, minimum norm, inverse solution that yields images of standardized current density with exact localization (Pascual-Marqui 2009), albeit with low resolution. sLORETA images consist of standardized current density at each of 6'239 cortical voxels (spatial resolution 5 mm) in Montreal Neurological Institute (MNI) space (Evans and Collins 1993).

sLORETA functional images were computed for each subject and condition separately in each of the seven classical independent frequency bands (Kubicki et al. 1979; Niedermeyer and Lopes da Silva 2005, p. 1234): delta (1.5-6 Hz), theta (6.5-8 Hz), alpha-1 (8.5-10 Hz), alpha-2 (10.5-12 Hz), beta-1 (12.5-18 Hz), beta-2 (18.5-21 Hz) and beta-3 (21.5-30 Hz) and in an additional eighth gamma frequency band (35-44 Hz), since this band reportedly is of interest in meditation research (Lehmann et al. 2001, 2012; Lutz et al. 2004).

All testing was done on the frequency band-wise normalized and log-transformed sLORETA images. Initial resting and final resting were compared using classical voxel-wise *t* tests. Correction for multiple testing was applied using nonparametric randomization (Nichols and Holmes 2002) implemented in the sLORETA software package. The two resting conditions did not differ significantly in any of the eight frequency bands. Therefore, for further comparisons, the sLORETA functional images for initial resting and final resting were averaged per subject and frequency band into a combined "resting" condition.

Zazen was then compared to resting using the same *t* test procedure with correction for multiple testing as above. Significant voxels were attributed to the corresponding Brodmann areas ("BAs"). BAs are reported using the MNI space with correction to Talairach space (Brett et al. 2002).

Correlations with meditation experience and age

Correlations (Pearson's *r*) were computed between participants' years of meditation experience and age and the sLORETA source localization results for Zazen and resting. Correction for multiple testing (Nichols and Holmes 2002) was applied.

2.2.4. Results

Intracortical functional source localization

The sLORETA analysis revealed significant differences between Zazen and resting at $p < 0.05$ after correction for multiple testing. The *t* threshold required for significance was $t = 5.86$. The following results met this threshold.

Current density in the alpha-1 and alpha-2 frequency bands increased during Zazen compared to resting in a large anterior right-hemispheric cluster as illustrated in Fig. 1. Table 1 specifies the number of significant voxels, the BAs and brains regions which extended from prefrontal areas including the insula to parts of the somatosensory and motor cortices. In the alpha-2 band, the cluster additionally included anterior temporal areas. There also was a small cluster in the left angular gyrus where alpha-1 and alpha-2 activity decreased.

Current density in the beta-1 and beta-2 frequency bands decreased in a large bilateral posterior cluster during Zazen compared to resting (Fig. 1). Table 1 shows that about 60 % of all voxels in this cluster were located in the visual cortices and in the somatosensory association cortex that includes the precuneus. The other nearly 40 % were located in the posterior cingulate cortex (PCC).

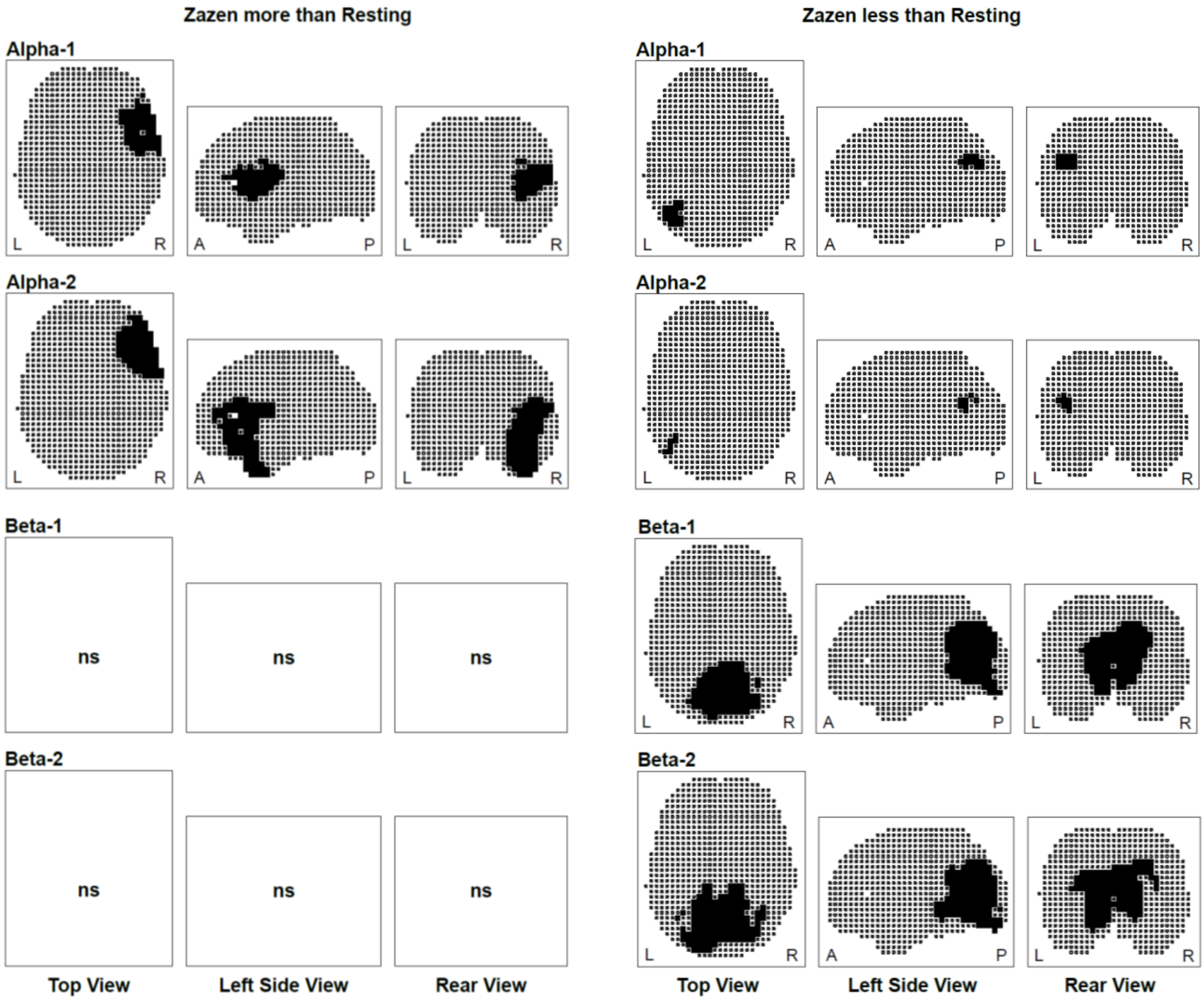

Fig. 1: Comparison of brain activity during Zazen and resting. Glass brain views, from *left* to *right*: axial, sagittal, and coronal views. *Left column*: Zazen had stronger activity than resting in the alpha-1 and alpha-2 EEG frequency bands. *Right column*: resting had stronger activity than Zazen in the alpha-1, alpha-2, beta-1 and beta-2 EEG frequency bands. *Dark voxels*: Differences between Zazen and resting at $p < 0.05$ after correction for multiple testing. *Light voxels*: sLORETA voxel space (MNI; left to right: -70 to +70 mm; posterior to anterior: -100 to +65 mm; inferior to superior: -45 to +70 mm)

Table 1: sLORETA frequency-band results of the comparison of Zazen versus resting

		Zazen more than resting							**Zazen less than resting**						
BA	**Region**	**LH**		**M**		**RH**			**LH**		**M**		**RH**		
Alpha-1 & Alpha-2 Frequency Bands		A1	A2	A1	A2	A1	A2	**Total**	A1	A2	A1	A2	A1	A2	**Total**
3	Primary somatosens. cortex	-	-	-	-	1	4	**5**	-	-	-	-	-	-	**-**
4	Primary motor cortex	-	-	-	-	5	-	**5**	-	-	-	-	-	-	**-**
6	Supplementary motor area	-	-	-	-	17	11	**28**	-	-	-	-	-	-	**-**
9	Dorsolateral prefrontal cortex	-	-	-	-	5	1	**6**	-	-	-	-	-	-	**-**
10	Anterior prefrontal cortex	-	-	-	-	-	10	**10**	-	-	-	-	-	-	**-**
11	Orbitofrontal area	-	-	-	-	-	15	**15**	-	-	-	-	-	-	**-**
13	Insular cortex	-	-	-	-	55	26	**81**	-	-	-	-	-	-	**-**
19	Associative visual cortex	-	-	-	-	-	-	-	1	-	-	-	-	-	**1**
20	Inferior temporal gyrus	-	-	-	-	-	1	**1**	-	-	-	-	-	-	**-**
21	Middle temporal gyrus	-	-	-	-	-	11	**11**	-	-	-	-	-	-	**-**
22	Superior temporal gyrus	-	-	-	-	5	3	**8**	-	-	-	-	-	-	**-**
38	Temporopolar area	-	-	-	-	-	54	**54**	-	-	-	-	-	-	**-**
39	Angular gyrus	-	-	-	-	-	-	-	24	10	-	-	-	-	**34**
42	primary auditory cortex	-	-	-	-	1	-	**1**	-	-	-	-	-	-	**-**
43	Primary gustatory cortex	-	-	-	-	11	-	**11**	-	-	-	-	-	-	**-**
44	pars opercularis of Broca	-	-	-	-	28	26	**54**	-	-	-	-	-	-	**-**
45	pars triangularis of Broca	-	-	-	-	25	27	**52**	-	-	-	-	-	-	**-**
46	Dorsolateral prefrontal cortex	-	-	-	-	8	23	**31**	-	-	-	-	-	-	**-**
47	Inferior prefontal gyrus	-	-	-	-	10	80	**90**	-	-	-	-	-	-	**-**
Beta-1 & Beta-2 Frequency Bands		B1	B2	B1	B2	B1	B2	**Total**	B1	B2	B1	B2	B1	B2	**Total**
7	Somatosensory assoc. cortex	-	-	-	-	-	-	-	14	11	8	6	55	25	**119**
17	Primary visual cortex	-	-	-	-	-	-	-	16	23	-	-	12	4	**55**
18	Secondary visual cortex	-	-	-	-	-	-	-	72	88	16	13	65	39	**293**
19	Associative visual cortex	-	-	-	-	-	-	-	19	61	1	-	54	37	**172**
22	Superior temporal gyrus	-	-	-	-	-	-	-	-	-	-	-	-	2	**2**
23	Ventral posterior cingulate	-	-	-	-	-	-	-	4	4	7	7	11	10	**43**
27	Parahippocampal gyrus	-	-	-	-	-	-	-	-	2	-	-	-	5	**7**
29	Retrosplenial cingulate	-	-	-	-	-	-	-	4	5	-	-	4	4	**17**
30	Part of cingulate cortex	-	-	-	-	-	-	-	28	36	3	3	32	39	**141**
31	Dorsal posterior cingulate	-	-	-	-	-	-	-	35	32	10	8	51	42	**178**
35	Perirhinal cortex	-	-	-	-	-	-	-	-	-	-	-	-	1	**1**
36	Parahippocampal cortex	-	-	-	-	-	-	-	-	-	-	-	-	2	**2**
39	Angular gyrus	-	-	-	-	-	-	-	-	3	-	-	5	9	**17**

Listed are the numbers of significant voxels by Brodmann area (BA), anatomical region and frequency bands (A1 = alpha-1, A2 = alpha-2, B1 = beta-1, B2 = beta-2)
LH = left hemisphere, M = midline, RH = right hemisphere.

Correlations with meditation experience and age

Neither meditation experience nor participants' age correlated significantly with the current density values of the sLORETA tomographies in Zazen or resting in any of the eight frequency bands.

2.2.5. Discussion

As hypothesized, Zazen compared to resting showed significant differences in activated brain areas. Differences concerned primarily increased right-hemispheric activity in the EEG alpha frequency bands and decreased bilateral posterior activity in the EEG beta frequency bands. Contrary to various earlier reports on EEG changes in meditation (Cahn and Polich 2006; Lutz et al. 2004), no effects in theta and gamma frequency bands were observed.

The functional significance of the EEG alpha frequency band activity is discussed controversially (Bazanova and Vernon 2013). Power in the alpha bands increases with internally directed attention (Cooper et al. 2003) and in a relaxed state of alert wakefulness (Işoğlu-Alkaç and Strüber 2006; Klimesch 1999; Müller et al. 1999). Alpha activity also increases with active memory processes (Palva and Palva 2007) and during sensory processing (Schürmann et al. 1997). The alpha rhythm was also reported to reflect the anticipatory processing of events (Karakas 1997; Klimesch 1999). These functions are in line with the meditator's stance of open monitoring during Zazen, that is of an alert wakefulness, expecting events such as thoughts (arising from memory) or sensory perceptions (e.g., body posture or external noises) to spontaneously occur with the intention of only witnessing them without further processing, i.e., without "getting attached" to them (see Austin 2013). We note that task-related posterior alpha reportedly implements an inhibitory function (e.g. Klimesch et al. 2007). But during Zazen compared to resting, we observed increased anterior and temporal alpha activity.

The observed increased alpha activity during Zazen exclusively concerned the right hemisphere. The right hemisphere has been linked to emotion processing (e.g., Keil et al. 2001; Laurian et al. 1991; Zhang and Zhou 2014). The right insula (BA 13), the right superior temporal gyrus (BA 22) and the right middle and superior frontal sulci (BAs 9 and 10) showed increased alpha activity during Zazen; these areas are part of the emotion circuitry of the brain (Gray et al. 2002, Lutz et al. 2008). BAs 9, 10 and 13 were also found to be thicker in experienced meditators (Lazar et al. 2005).

Increased alpha activity in the prefrontal cortex (BAs 44, 45, 46 and 47), the insula (BA 13) and the somatosensory cortex (BA 3) as observed in our analysis presumably is related to self-reference based on momentary experience (Farb et al. 2007). This is in line with Austin's (2013) description of the Zazen practice as favoring the momentary experience. According to Austin, this leads to a calming of the awareness which allows introspective memory processes to emerge. Right prefrontal and insular areas were reported to be engaged in response inhibition (Dambacher et al. 2014; Eckert et al. 2009). Thus, in addition to the focus on momentary experience, the increased right prefrontal and insular alpha activity also agrees with an increased executive control needed for upholding the detached non-discursive mental state during Zazen.

The increased alpha activity in sensory and motor-related areas (BAs 3, 4, 6) in our results might reflect the increased moment-to-moment proprioception, including automatic information processing on body posture while sitting erect on a meditation cushion during Zazen.

In sum, the increased right-hemispheric alpha activity during Zazen thus on the one hand confirms our hypothesis of increased memory and emotion processing during meditation, and on the other hand reflects the present-centeredness of experience and the maintenance of a detached non-discursive stance during meditation.

About 60 % of the voxels with decreased beta frequency band activity during Zazen were in the visual cortices (BAs 17, 18, 19) and in BA7 that includes the precuneus, encompassing the dorsal visual stream (Ungerleider and Mishkin 1982). The reduction in activity in BAs 17, 18 and 19 during Zazen suggests reduced visual imagery (Kosslyn et al. 1993, 1999). This is especially noteworthy since our practitioners had their eyes only two-thirds closed during Zazen compared to having them completely closed during resting. The precuneus has been reported to be involved in self-related mental imagery (Cavanna and Trimble 2006). The reduced activation of this dorsal visual stream during meditation might reflect the decreased need of vision-for-action (Goodale 2011; Goodale and Milner 1992).

The other nearly 40% of the voxels showing decreased beta activity during Zazen were located in the posterior cingulate cortex (PCC; BAs 23, 29, 30 and 31). The deactivation of this important hub of the DMN has been related to effortless awareness (Garrison et al. 2013a) and was also found deactivated in an fMRI study during focused attention meditation (Garrison et al. 2013b). PCC deactivation reportedly reflects increased present-centered awareness, whereas PCC activation is related to being caught up in mental content and is associated with decreased attention (Brewer et al. 2013). Our results thus suggest that during meditation the practitioners are less engaged in their thoughts and more centered in the present moment. Unfortunately, in the present study, no subjective reports were gathered about mentation during Zazen and resting, which makes this interpretation tentative. On the other hand, an attentive, yet detached present-centeredness and a reduced amount of spontaneous thoughts correspond to reported descriptions of the subjective experience during Zazen meditation (Austin 2013). It has been suggested that the PCC implements evaluation or judgment of experience (Legrand and Ruby 2009; Qin and Northoff 2011). Thus, the PCC deactivation during Zazen also fits the description of greater detachment from perceptions claimed to be present during meditation.

The angular gyrus (BA39) showed decreased activity in the alpha (left hemispheric) and beta (bilateral) frequency bands during Zazen. The angular gyrus is an important hub of the posterior part of the DMN which has been shown to be active during memory-based decision making (Sestieri et al. 2011) and semantic processing (Seghier et al. 2010). In a lexical decision task (discriminating words from nonwords) including the instruction to refocus on breathing after each decision, Zen meditators showed a shortened post-stimulus tail and decreased post-stimulus left angular gyrus BOLD activity compared to controls (Pagnoni et al 2008). This was interpreted as indicating a faster refocusing of attention on the breath in meditators and a reduction in conceptual processing. A reduction in conceptual processing might be an indicator for non-dual awareness during Zazen, thus adding an aspect to Zazen outside the classification as an open monitoring practice (Josipovic 2010, Travis and Shear 2010a, b). Future research needs to take into account subjective reports in order to get information on the dual versus non-dual aspect of experience during the practice of Zazen.

In sum, the posterior alpha and beta decreases suggest an increased present-centeredness that is detached, nonjudgmental and non-discursive with reduced semantic processing and self-reference during Zazen compared to resting.

How do our results compare to those based on similar analysis methods and concerning other meditation practices? There are only three studies that tested practicing meditation versus no-task resting and that used intracerebral EEG source analysis (Lavallee et al. 2011; Travis et al. 2010; Yamamoto et al. 2006). The practice in the study on concentration meditation (Lavallee et al., 2011) obviously would be classified as focused attention meditation, whereas our Zazen practice is an open monitoring meditation (Lutz et al. 2008). The practice used in the studies on transcendental meditation (Travis et al. 2010; Yamamoto et al. 2006) would be classified as *automatic self-transcending* meditation in another classification scheme (Travis and Shear 2010a). Our present results were different from both concentration on breathing and from transcendental meditation.

We note that age and meditation experience of the participants did not correlate significantly with our sLORETA current density images during Zazen or resting in any frequency band. Other studies have reported correlations between meditation experience and brain electric measures in some but not all frequency bands (e.g., Cahn et al. 2010; Lutz et al. 2004; Murata et al. 1994; Travis and Arenander 2006). Berkovich-Ohana et al. (2012) did not find a correlation with experience in their EEG gamma band study, while Brefczynski-Lewis et al. (2007) reported an inverted U-shaped dependence of results on experience, with very experienced meditators having again minimal effects on results. One possible explanation for our lack of correlations with experience could be due to our sample of participants consisting of experienced meditators only: There were no beginners, and the least experienced participant had already 5 years of meditation experience. A wider range of meditation experience might have been informative.

A potential limitation of the present study concerns the resting state of our meditators. It is known that long-term meditation alters the resting state EEG (e.g., Aftanas and Golosheykin 2005; Lutz et al. 2004; Tebecis 1975; Tei et al. 2009). Therefore, it is possible that the resting state of our experienced meditators is different from the resting state of non-meditators. Our reported differences between Zazen and resting might be affected by the possibly altered resting state of our meditators. Brewer et al. (2011) also brought up this problem and ventured to suggest an altered default mode during resting in meditators. A longitudinal approach could shed light on this issue or the direct comparison of the resting state of Zen meditators with the resting state of a matched control group consisting of non-meditators.

To elucidate the idiosyncrasies of the different types of meditation practices, future studies should directly compare Zazen as an open monitoring practice with focused attention meditation practices (e.g., breath counting) or automatic self-transcending (transcendental meditation).

Conclusion

In conclusion, the results confirmed our hypotheses of different activated brain areas during Zazen compared to no-task resting and specifically of the involvement of parts of the DMN. The findings reflect enhanced present-centeredness with automated and effortless memory and emotion processing, reduced conceptual thinking and self-reference, greater detachment from perceptions and body posture-related processing during Zazen compared to resting.

2.2.6. Acknowledgments

Supported in part by Grant Nr. 44/06 from the Bial Foundation, S. Mamede do Coronado, Portugal.

2.2.7. References

Aftanas L, Golosheykin S (2005) Impact of regular meditation practice on EEG activity at rest and during evoked negative emotions. Int J Neurosci 115(6):893-909

Austin JH (2011) Meditating selflessly: practical neural zen. MIT Press, Cambridge MA

Austin JH (2013) Zen and the brain: mutually illuminating topics. Front Psychol 4:784. doi:10.3389/fpsyg.2013.00784

Bazanova OM, Vernon D (2013) Interpreting EEG alpha activity. Neurosci Biobehav Rev. doi:10.1016/j.neubiorev.2013.05.007

Becker DE, Shapiro D (1981) Physiological responses to clicks during Zen, Yoga, and TM meditation. Psychophysiology 18(6):694-699

Berkovich-Ohana A, Glicksohn J, Goldstein A (2012) Mindfulness-induced changes in gamma band activity - implications for the default mode network, self-reference and attention. Clin Neurophysiol 123(4):700-10. doi:10.1016/j.clinph.2011.07.048

Binder JR, Frost JA, Hammeke TA, Bellgowan PS, Rao SM, Cox RW (1999) Conceptual processing during the conscious resting state. A functional MRI study. J Cogn Neurosci 11(1):80-95

Brefczynski-Lewis JA, Lutz A, Schaefer HS, Levinson DB, Davidson RJ (2007) Neural correlates of attentional expertise in long-term meditation practitioners. Proc Natl Acad Sci USA 104(27):11483-11488

Brett M, Johnsrude IS, Owen AM (2002) The problem of functional localization in the human brain. Nat Rev Neurosci 3(3):243-9

Brewer JA, Worhunsky PD, Gray JR, Tang YY, Weber J, Kober H (2011) Meditation experience is associated with differences in default mode network activity and connectivity. Proc Natl Acad Sci USA 108(50):20254-20259. doi:10.1073/pnas.1112029108

Brewer JA, Garrison KA, Whitfield-Gabrieli S (2013) What about the "self" is processed in the posterior cingulate cortex? Front Hum Neurosci 7:647

Britz J1, Van De Ville D, Michel CM (2010) BOLD correlates of EEG topography reveal rapid resting-state network dynamics. Neuroimage 52(4):1162-1170. doi:10.1016/j.neuroimage.2010.02.052

Buckner RL, Andrews-Hanna JR, Schacter DL (2008) The brain's default network: anatomy, function, and relevance to disease. Ann N Y Acad Sci 1124:1-38. doi:10.1196/annals.1440.011

Cahn BR, Polich J (2006) Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychol Bull 132(2):180-211

Cahn BR, Delorme A, Polich J (2010) Occipital gamma activation during Vipassana meditation. Cogn Process 11(1):39-56. doi:10.1007/s10339-009-0352-1

Cavanna A, Trimble M (2006) The precuneus: a review of its functional anatomy and behavioural correlates. Brain 129 (Pt 3):564–583. doi:10.1093/brain/awl004

Chapman LJ, Chapman JP (1987) The measurement of handedness. Brain Cogn 6(2):175-183

Cooper NR, Croft RJ, Dominey SJ, Burgess AP, Gruzelier JH (2003) Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. Int J Psychophysiol 47(1):65-74

Dambacher F, Sack AT, Lobbestael J, Arntz A, Brugmann S, Schuhmann T (2014) The role of right prefrontal and medial cortex in response inhibition: interfering with action restraint and action cancellation using transcranial magnetic brain stimulation. J Cogn Neurosci 26(8):1775-84. doi:10.1162/jocn_a_00595

Dogen (1243/2001) Treasury of the eye of the true dharma, Book 11. Principles of Zazen (Zazen gi). http://scbs.stanford.edu/sztp3/translations/shobogenzo/translations/zazengi/zazengi.translation.html. Accessed 31 March 2014

Dunn BR, Hartigan JA, Mikulas WL (1999) Concentration and mindfulness meditations: unique forms of consciousness? Appl Psychophysiol Biofeedback 24(3):147-65

Eckert MA, Menon V, Walczak A, Ahlstrom J, Denslow S, Horwitz A, Dubno JR (2009) At the heart of the ventral attention system: the right anterior insula. Hum Brain Mapp 30(8):2530-41. doi:10.1002/hbm.20688

Evans AC, Collins DL (1993) A 305-member MRI-based stereotactic atlas for CBF activation studies. Proceedings of the 40th Annual Meeting of the Society for Nuclear Medicine

Farb NA, Segal ZV, Mayberg H, Bean J, McKeon D, Fatima Z, Anderson AK (2007) Attending to the present: mindfulness meditation reveals distinct neural modes of self-reference. Soc Cogn Affect Neurosci 2(4):313-322. doi:10.1093/scan/nsm030

Garrison KA, Santoyo JF, Davis JH, Thornhill TA 4th, Kerr CE, Brewer JA. (2013a) Effortless awareness: using real time neurofeedback to investigate correlates of posterior cingulate cortex activity in meditators' self-report. Front Hum Neurosci 7:440. doi:10.3389/fnhum.2013.00440

Garrison KA, Scheinost D, Worhunsky PD, Elwafi HM, Thornhill TA 4th, Thompson E, Saron C, Desbordes G, Kober H, Hampson M, Gray JR, Constable RT, Papademetris X, Brewer JA (2013b) Real-time fMRI links subjective experience with brain activity during focused attention. Neuroimage 81:110–118

Geselowitz DB (1998) The zero of potential. IEEE Eng Med Biol Mag 17(1):128-132

Goodale MA (2011) Transforming vision into action. Vision Res 51(14):1567-1587. doi:10.1016/j.visres.2010.07.027

Goodale MA, Milner AD (1992) Separate pathways for perception and action. Trends in Neurosci 15(1):20-25. doi:10.1016/0166-2236(92)90344-8

Gray JR, Braver TS, Raichle ME (2002) Integration of emotion and cognition in the lateral prefrontal cortex. Proc Natl Acad Sci USA 99:4115-4120

Greicius MD, Srivastava G, Reiss AL, Menon V (2004) Default-mode network activity distinguishes Alzheimer's disease from healthy aging: evidence from functional MRI. Proc Natl Acad Sci USA 101(13):4637-42

Gusnard DA, Akbudak E, Shulman GL, Raichle ME (2001) Medial prefrontal cortex and self-referential mental activity: relation to a default mode of brain function. Proc Natl Acad Sci USA 98(7):4259-64

Huang HY, Lo PC (2009) EEG dynamics of experienced Zen meditation practitioners probed by complexity index and spectral measure. J Med Eng Technol 33(4):314-321. doi:10.1080/03091900802602677

Işoğlu-Alkaç U, Strüber D (2006) Necker cube reversals during long-term EEG recordings: sub-bands of alpha activity. Int J Psychophysiol 59(2):179-89

Josipovic Z (2010) Duality and nonduality in meditation research. Conscious Cogn 19(4):1119-21. doi:10.1016/j.concog.2010.03.016

Karakas S (1997) A descriptive framework for information processing: an integrative approach. Int J Psychophysiol 26(1-3):353-68.

Kasamatsu A, Hirai T (1966) An electroencephalographic study on the zen meditation (Zazen). Folia Psychiatr Neurol Jpn 20(4):315-336

Keil A, Müller MM, Gruber T, Wienbruch C, Stolarova M, Elbert T (2001) Effects of emotional arousal in the cerebral hemispheres: a study of oscillatory brain activity and event-related potentials. Clin Neurophysiol 112:2057–2068

Klimesch W (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev 29(2-3):169-195

Klimesch W, Sauseng P, Hanslmayr S (2007) EEG alpha oscillations: the inhibition–timing hypothesis. Brain Res Rev 53:63-88

Kosslyn SM, Alpert NM, Thompson WL, Maljkovic V, Weise SB, Chabris CF, Hamilton SE, Rauch SL, Buonanno FS (1993) Visual mental imagery activates topographically organized visual cortex: PET investigations. J Cogn Neurosci 5(3):263-87. doi:10.1162/jocn.1993.5.3.263

Kosslyn SM, Pascual-Leone A, Felician O, Camposano S, Keenan JP, Thompson WL, Ganis G, Sukel KE, Alpert NM (1999) The role of area 17 in visual imagery: convergent evidence from PET and rTMS. Science 284(5411):167-170

Kubicki S, Herrmann WM, Fichte K, Freund G (1979) Reflections on the topics: EEG frequency bands and regulation of vigilance. Pharmakopsychiatr Neuropsychopharmakol 12:237-245

Kubota Y, Sato W, Toichi M, Murai T, Okada T, Hayashi A, Sengoku A (2001) Frontal midline theta rhythm is correlated with cardiac autonomic activities during the performance of an attention demanding meditation procedure. Brain Res Cogn Brain Res 11(2):281-287

Laufs H, Krakow K, Sterzer P, Eger E, Beyerle A, Salek-Haddadi A, Kleinschmidt A (2003) Electroencephalographic signatures of attentional and cognitive default modes in spontaneous brain activity fluctuations at rest. Proc Natl Acad Sci USA 100:11053–11058

Laurian S, Bader M, Lanares J, Oros L (1991) Topography of event-related potentials elicited by visual emotional stimuli. Int J Psychophysiol 10(3):231-238

Lavallee CF, Hunter MD, Persinger MA (2011) Intracerebral source generators characterizing concentrative meditation. Cogn Process 12(2):141-150. doi:10.1007/s10339-011-0394-z

Lazar SW, Kerr CE, Wasserman RH, Gray JR, Greve DN, Treadway MT, McGarvey M, Quinn BT, Dusek JA, Benson H, Rauch SL, Moore CI, Fischl B (2005) Meditation experience is associated with increased cortical thickness. NeuroReport 16(17):1893-1897

Legrand D, Ruby P (2009) What is self-specific? Theoretical investigation and critical review of neuroimaging results. Psychol Rev 116(1):252-282. doi:10.1037/a0014172

Lehmann D, Faber PL, Achermann P, Jeanmonod D, Gianotti LR, Pizzagalli D (2001) Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. Psychiatry Res 108(2):111-121

Lehmann D, Faber PL, Tei S, Pascual-Marqui RD, Milz P, Kochi K (2012) Reduced functional connectivity between cortical sources in five meditation traditions detected with lagged coherence using EEG tomography. Neuroimage 60(2):1574-1586. doi:10.1016/j.neuroimage.2012.01.042

Lou HC, Luber B, Crupain M, Keenan JP, Nowak M, Kjaer TW, Sackeim HA, Lisanby SH (2004) Parietal cortex and representation of the mental Self. Proc Natl Acad Sci USA 101(17):6827-32

Lutz A, Greischar LL, Rawlings NB, Ricard M, Davidson RJ (2004) Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. Proc Natl Acad Sci USA 101(46):16369-16373

Lutz A, Brefczynski-Lewis J, Johnstone T, Davidson RJ (2008) Regulation of the neural circuitry of emotion by compassion meditation: effects of meditative expertise. PLoS One 3(3):e1897. doi:10.1371/journal.pone.0001897

Makeig S, Jung TP (1995) Changes in alertness are a principal component of variance in the EEG spectrum. Neuroreport 7(1):213-216

Mason MF, Norton MI, Van Horn JD, Wegner DM, Grafton ST, Macrae CN (2007) Wandering minds: the default network and stimulus-independent thought. Science 315(5810):393-5

Mesulam MM (1990) Large-scale neurocognitive networks and distributed processing for attention, language, and memory. Ann Neurol 28:597–613

Müller TJ, Federspiel A, Fallgatter AJ, Strik WK (1999) EEG signs of vigilance fluctuations preceding perceptual flips in multistable illusionary motion. NeuroReport 10(16):3423-3427

Murata T, Koshino Y, Omori M, Murata I, Nishio M, Sakamoto K, Horie T, Isaki K (1994) Quantitative EEG study on zen meditation (Zazen). Jpn J Psychiatr Neurol 48(4):881-890

Nichols TE, Holmes AP (2002) Nonparametric permutation tests for functional neuroimaging: a primer with examples. Hum Brain Mapp 15:1-25

Niedermeyer E, Lopes da Silva F (2005) Electroencephalography: basic principles, clinical applications, and related fields, 5th ed. Lippincott Williams Wilkins, Philadelphia.

Nuwer MR, Comi G, Emerson R, Fuglsang-Frederiksen A, Guérit JM, Hinrichs H, Ikeda A, Luccas FJ, Rappelsburger P (1998) IFCN standards for digital recording of clinical EEG. International Federation of Clinical Neurophysiology. Electroencephalogr Clin Neurophysiol 106:259-261

O'Gorman RL, Poil SS, Brandeis D, Klaver P, Bollmann S, Ghisleni C, Luchinger R, Martin E, Shankaranarayanan A, Alsop DC, Michels L (2013) Coupling between resting cerebral perfusion and EEG. Brain Topogr 26(3):442-457

Pagnoni G, Cekic M, Guo Y (2008) "Thinking about not-thinking": neural correlates of conceptual processing during Zen meditation. PLoS One 3(9):e3083. doi:10.1371/journal.pone.0003083

Palva S, Palva JM (2007) New vistas for alpha-frequency band oscillations. Trends Neurosci 30(4):150-158

Pascual-Marqui RD (2002) Standardized low resolution brain electromagnetic tomography (sLORETA): technical details. Methods Find Exp Clin Pharmacol 24(Suppl. D):5-12

Pascual-Marqui RD (2009) Theory of the EEG inverse problem. In: Tong S, Thakor NV (eds) Quantitative EEG analysis: methods and clinical applications. Artech House, Boston, pp 121-140

Pascual-Marqui RD, Michel CM, Lehmann D (1994) Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. Int J Psychophysiol 18(1):49-65

Pascual-Marqui RD, Lehmann D, Koenig T, Kochi K, Merlo MC, Hell D, Koukkou M (1999) Low resolution brain electromagnetic tomography (LORETA) functional imaging in acute, neuroleptic-naive, first-episode, productive schizophrenia. Psychiatry Res 90(3):169-179

Qin P, Northoff G (2011) How is our self related to midline regions and the default-mode network? Neuroimage 57(3):1221-1233. doi:10.1016/j.neuroimage.2011.05.028

Raffone A, Srinivasan N (2010) The exploration of meditation in the neuroscience of attention and consciousness. Cogn Process 11(1):1-7. doi:10.1007/s10339-009-0354-z

Raichle ME, MacLeod AM, Snyder AZ, Powers WJ, Gusnard DA, Shulman GL (2001) A default mode of brain function. Proc Natl Acad Sci USA 98(2):676-682

Ruchkin D (2005) EEG coherence. Int J Psychophysiol 57(2):83-85

Schürmann M, Başar-Eroglu C, Başar E (1997) A possible role of evoked alpha in primary sensory processing: common properties of cat intracranial recordings and human EEG and MEG. Int J Psychophysiol 26(1-3):149-170

Seghier ML, Fagan E, Price CJ (2010) Functional subdivisions in the left angular gyrus where the semantic system meets and diverges from the default network. J Neurosci 30(50):16809-16817. doi:10.1523/JNEUROSCI.3377-10.2010

Sestieri C, Corbetta M, Romani GL, Shulman GL (2011) Episodic memory retrieval, parietal cortex, and the default mode network: functional and topographic analyses. J Neurosci 31(12):4407-4420. doi:10.1523/JNEUROSCI.3335-10.2011

Shapiro SL, Walsh R (2003) An analysis of recent meditation research and suggestions for future directions. The Humanistic Psychologist, 31:2-3, 86-114. doi: 10.1080/08873267.2003.9986927

Takahashi T, Murata T, Hamada T, Omori M, Kosaka H, Kikuchi M, Yoshida H, Wada Y (2005) Changes in EEG and autonomic nervous activity during meditation and their association with personality traits. Int J Psychophysiol 55(2):199-207

Tebēcis AK (1975) A controlled study of the EEG during transcendental meditation: comparison with hypnosis. Folia Psychiatr Neurol Jpn 29(4):305-313

Tei S, Faber PL, Lehmann D, Tsujiuchi T, Kumano H, Pascual-Marqui RD, Gianotti LRR, Kochi K (2009) Meditators and non-meditators: EEG source imaging during resting. Brain Topogr 22:158-165. doi:10.1007/s10548-009-0107-4

Travis F, Arenander A (2006) Cross-sectional and longitudinal study of effects of transcendental meditation practice on interhemispheric frontal asymmetry and frontal coherence. Int J Neurosci 116(12):1519-1538

Travis F, Shear J (2010a) Focused attention, open monitoring and automatic self-transcending: Categories to organize meditations from Vedic, Buddhist and Chinese traditions. Conscious Cogn 19(4):1110-1118. doi:10.1016/j.concog.2010.01.007

Travis F, Shear J (2010b) Reply to Josipovic: Duality and non-duality in meditation research. Conscious Cogn 19(4):1122-1123. doi:10.1016/j.concog.2010.04.003

Travis F, Haaga DA, Hagelin J, Tanner M, Arenander A, Nidich S, Gaylord-King C, Grosswald S, Rainforth M, Schneider RH (2010) A self-referential default brain state: patterns of coherence, power, and eLORETA sources during eyes-closed rest and Transcendental Meditation practice. Cogn Process 11(1):21-30. doi:10.1007/s10339-009-0343-2

Ungerleider LG, Mishkin M (1982) Two cortical visual systems. In Ingle DJ, Goodale MA, Mansfield RJW (eds) Analysis of visual behavior. MIT Press, Boston, pp 549-586

Yamamoto S, Kitamura Y, Yamada N, Nakashima Y, Kuroda S (2006) Medial profrontal cortex and anterior cingulate cortex in the generation of alpha activity induced by transcendental meditation: a magnetoencephalographic study. Acta Med Okayama 60(1):51-58

Yu X, Fumoto M, Nakatani Y, Sekiyama T, Kikuchi H, Seki Y, Sato-Suzuki I, Arita H (2011) Activation of the anterior prefrontal cortex and serotonergic system is associated with improvements in mood and EEG changes induced by Zen meditation practice in novices. Int J Psychophysiol 80(2):103-11. doi:10.1016/j.ijpsycho.2011.02.004

Zhang J, Zhou R (2014) Individual differences in automatic emotion regulation affect the asymmetry of the LPP component. PLoS One 9(2):e88261. doi:10.1371/

journal.pone.0088261

2.3. Study III- Reduced functional connectivity between cortical sources in five meditation traditions detected with lagged coherence using EEG tomography[3]

2.3.1. Abstract

Brain functional states are established by functional connectivities between brain regions. In experienced meditators (13 Tibetan Buddhists, 15 QiGong, 14 Sahaja Yoga, 14 Ananda Marga Yoga, 15 Zen), 19-channel EEG was recorded before, during and after that meditation exercise which their respective tradition regards as route to the most desirable meditative state. The head surface EEG data were recomputed (sLORETA) into 19 cortical regional source model time series. All 171 functional connectivities between regions were computed as 'lagged coherence' for the eight EEG frequency bands (delta through gamma). This analysis removes ambiguities of localization, volume conduction-induced inflation of coherence, and reference-dependence. All significant differences (corrected for multiple testing) between meditation compared to no-task rest before and after meditation showed lower coherence during meditation, in all five traditions and eight (inhibitory as well as excitatory) frequency bands. Conventional coherence between the original head surface EEG time series very predominantly also showed reduced coherence during meditation. The topography of the functional connectivities was examined via PCA-based computation of principal connectivities.When going into and out of meditation, significantly different connectivities revealed clearly different topographies in the delta frequency band and minor differences in the beta-2 band. The globally reduced functional interdependence between brain regions in meditation suggests that interaction between the self process functions is minimized, and that constraints on the self process by other processes are minimized, thereby leading to the subjective experience of non-involvement, detachment and letting go, as well as of all-oneness and dissolution of ego borders during meditation.

2.3.2. Introduction

Meditation is currently an important topic in affective and cognitive neuroscience. Many physiological and psychological aspects of meditation practice have been reported applying very different measurement and analysis approaches (e.g. Luders et al., 2009; Lutz et al., 2009; van den Hurk et al., 2010; for an earlier review of the extended literature see Cahn and Polich, 2006).

Brain states of higher cognitive functions such as meditation are implemented as spatially

[3] This study has been published: Lehmann D, Faber PL, Tei S, Pascual-Marqui RD, Milz P, Kochi K. (2012). Reduced functional connectivity between cortical sources in five meditation traditions detected with lagged coherence using EEG tomography. Neuroimage **60**(2): 1574-1586.

distributed dynamical neuronal networks (Mesulam, 1990; Tononi et al., 1998) that constitute webs of functional connections between brain regions. The brain mechanisms of a functional state are appropriately described by the functional connections between the active brain regions (Singer, 2009). Such descriptions can document characteristic changes between various mental states (e.g. Burgess and Ali, 2002; Mizuhara et al., 2005; Stam, 2000; Walter et al., 1967; White et al., 2009).

The EEG measure of functional connectivity implemented as coherence between head surface recorded EEG timeseries has been used to assess brain states during meditation. These studies have shown increased EEG coherence during Transcendental Meditation (e.g. Gaylord et al., 1989; Levine, 1976; Travis and Orme-Johnson, 1989; Travis et al., 2002, 2010); experienced practitioners of Transcendental Meditation as well as novices showed increased alpha coherence compared to resting (Dillbeck and Bronson, 1981; Travis, 2001; Travis and Wallace, 1999). Zen meditation reportedly increased alpha coherence in meditation novices (Murata et al., 2004). Sahaja Yoga in long-term meditators produced theta coherence increases between some brain areas but decreases between other areas; in short term meditators, theta coherence only decreased (Aftanas and Golocheikine, 2001). Also, increase of phase locking in gamma frequency during Buddhist meditation has been reported (Lutz et al., 2004) but the authors stressed that phase locking differs from coherence (although both are measures of ‘similarity’ between pairs of signals measured at two locations, and are thus interpreted as measures of connectivity between the locations).

However, it has been questioned to what extent conventional computation of head surface EEG coherence reveals true functional connectivity between the brain regions under the locations of the recording electrodes because neuronal electric sources do not necessarily project radially to the scalp; computing EEG coherence between intracerebral generator model sources avoids this problem (see also Ruchkin, 2005). Also, the confounding effect of volume conduction in the conventional computation of EEG coherence has been criticized, and omission of zero phase angle coherence values was proposed as remedy (Nolte et al., 2004). Moreover, since the waveform of an EEG time series from a head surface electrode depends on the chosen reference, conventional head surface coherence is referencedependent (examples in Lehmann et al., 2006).

The present study examines the intracortical functional connectivity of brain electric activity during meditation and during task-free resting preceding and following meditation. The analysis applies ‘lagged’ coherence that partials out the effect of zero phase angle coherence (Pascual- Marqui, 2007; Pascual-Marqui et al., 2011), thereby removing the volume conduction artifact. Further, it applies the method to cortical time series of electric neuronal generator activity estimated via LORETA-based source modeling of the head surface-recorded EEG data (sLORETA, Pascual-Marqui, 2002) which removes the ambiguity of source localization. Analyzing the source model-generated time series also solves the problem of reference dependence present in the head surface EEG signals. Conventionally computed coherence between the originally recorded head surface EEG time series is reported for comparison.

There are obvious differences between meditation traditions and meditation techniques. Considering these differences, taxonomies of meditation techniques have been proposed (e.g. Fischer, 1971; Lutz et al., 2008; Mikulas, 1990; Travis and Shear, 2010; distinctions were emphasized by Kabat-Zinn, 1982). Data available to us for the present study were from experienced practitioners of five different meditation traditions: Tibetan Buddhism, QiGong, Sahaja Yoga, Ananda Marga Yoga, and Zen. The meditators were recorded while performing that meditation exercise which their respective tradition regards as the route to the most desirable meditative state; recordings during no-task resting before and after meditation were also done. Because of the obvious differences between meditation traditions, the data from each of the five groups were analyzed separately.

On the other hand, apparently there are common goals resulting in common subjective experiences of the meditation practices across schools and traditions (Brewer et al., 2011; Cahn and Polich, 2006; Fischer, 1971; Goleman, 1996; Hinterberger et al., 2011; Kabat-Zinn, 1990; Walsh, 1982): The handling of the contents of consciousness (avoiding intruding unintended thoughts as described in terms such as e.g. letting go, benevolent disregard, detachment), and the quality of the conscious self-awareness (attaining a pleasant, peaceful state of mind as described in terms such as all-oneness, bliss, oceanic feeling, transcending, expanded consciousness).

The present study separately analyzed each of the five groups in order to examine how brain electric functional connectivities differ between resting and meditation, and whether changes into and out of meditation are compensatory. Analyzing the brain activity of meditators from different traditions resulted in the surprising finding that the optimal meditation state in all the five traditions is characterized by reduced intracortical functional connectivity compared to no-task resting.

2.3.3. Methods

2.3.3.1. Participants

We analyzed EEG data from five groups of experienced meditators that were available to us. The meditators belonged to different meditation traditions: 13 Tibetan Buddhists (TB), 15 QiGong practitioners (QG), 14 Sahaja Yoga practitioners (SY), 14 Ananda Marga Yoga practitioners (AY) and 15 Zen practitioners (ZA). The study was approved by the Ethics Committee of the Tokyo University Medical School (#1364) for the TB, QG, SY and AY, and by the Ethics Committee of the University Hospital Zurich for the ZA. The participants were fully informed about the goal and methods of the study, and gave their written consent.

Gender, and mean years of age, and mean years of meditation experience (we asked for the year when the meditator had started practicing meditation everyday) with standard errors and ranges of the meditators of the five traditions are listed in Table 1. All participants used their right hands for writing. The participants had no history of head trauma or mental diseases, did not take centrally active medication and were not drug users.

The TB were Lamas from Tibet and India, from the Nyingmapa and Kagyupa traditions, who temporarily stayed in Taipei for missionary work; they meditate daily for at least 60 minutes. The QG were Taiwanese lay people who studied under Qigong Master Feng-San Lee at Taipei; they meditate daily for at least 45 minutes. The SY were Taiwanese lay people who meditate daily for at least 30 minutes; the AY were westerner and Hindu monks and nuns who live in Taipei; they meditate daily at least for 2 hours; the ZA were Swiss lay people who regularly participate in meditation exercises at the Zen Dojo Zurich, a Soto Zen institution; they meditate daily for at least 60 minutes. The meditators of all five groups have the habit to participate occasionally in retreats.

TB were paid 1000 NT$/person; QG, SY and AY were unpaid volunteers; ZA were paid 40 CHF/person.

2.3.3.2. Recording

The EEG recordings of TB, QG, SY and AY were done at the EEG Laboratory of the Department of Neurology, General Veterans Hospital in Taipei, during September-December 2006. The EEG was recorded versus combined ears (the 19 standard EEG channels of the international 10/20 system were analyzed), together with eye movement, muscle and ECG channels, using silver/silver-chloride electrodes with the Hospital's 32-channel Nicolet Voyager Digital EEG system; EEG was band passed from 1 to 70 Hz and digitized at 256 samples/s.

The EEG recordings of ZA were done at the KEY Laboratory at the University Hospital of Psychiatry in Zurich, using a 64-channel M&I system (Prague, Czech Republic), 58 electrodes were attached (Easycap System Munich, Germany) at locations of the international 10–10 system (Nuwer et al., 1998) with 2 additional channels for eye movement recordings. EEG was band-passed from 0.5 to 125 Hz and digitized at 250 samples/s, off-line up-sampled to 256 samples/s.

2.3.3.3. Protocol

The protocol comprised 6 sequential recording conditions, but only conditions 1, 3 and 4 were done in all five groups:

1- Initial resting: 20 s eyes opened, 40 s eyes closed; 4 cycles. TB, SY, and AY: lotus position, QG: sitting on stool, ZA: sitting on chair with armrests. For TB, QG, SY and AY, experimenters aimed at obtaining at least 20 s of artifact-free data and therefore often extended the planned eyes-closed recording times, but no more than the first 160 s of artifact-free data were used. The ZA recordings exactly followed the protocol.
2- Breath counting (not used in present analysis) only in TB, QG, SY and AY: 5 minutes. Participants were asked to silently count their inspirations from 1 to 10, continually repeating this sequence during the entire 5 minutes.
3- Meditation (described below): TB, QG, SY, and AY: 20 min, ZA: 60min.
4- Final resting: see initial resting.
5- Mental arithmetic (not used in present analysis) only in QG, SY, and AY: 5 minutes, participants were asked to continually subtract 7, starting from 1000, and restarting from 1000 if zero was reached or track of calculation was lost.
6- Post arithmetic resting (not used in present analysis) only in QG, SY, and AY: see initial resting.

In sum, conditions 1 (initial resting), 3 (meditation) and 4 (final resting) were done in all five participating groups; these three conditions were used in the present analysis.

Table 1.
Demographics of the meditators of the five traditions (groups).

	Number		Years of age				Years of meditation experience			
	total	men	mean	SEM	max	min	mean	SEM	max	min
Tibetan Buddhists	13	13	38.9	2.3	58	27	12.2	1.9	25	1
QiGong	15	15	37.2	2.0	49	25	6.6	0.9	13	2
Sahaja Yoga	14	4	43.9	2.7	63	26	8.5	1.6	20	1
Ananda Marga Yoga	14	9	45.2	2.1	56	31	16.9	2.4	33	5
Zen	15	9	42.0	2.0	56	29	12.3	1.4	21	5

2.3.3.4. Meditation

Position: TB, SY, AY, and ZA: sitting in lotus position; QG: sitting on a stool.

Eyes: TB, QG, SY, and AY: eyes closed; ZA: eyes half closed, facing the wall at a distance of about 1 meter.

The meditation practices in the five traditions that lead to optimal meditation states were, in keywords (selected from descriptions given by the representative of each group):

TB: dissolution into Buddha, letting thoughts pass by, reaching mental emptiness, ego-dissolution.

QG: diminution of spontaneous thoughts, reaching higher sensory awareness, immersing in ‘Qigong’ (gentle slow arm movements in synchrony with breathing), transcending.

SY: self realization, growth of self awareness, thoughtless awareness.

AY: withdrawal of the senses, transcendence into pure, limitless supreme consciousness.

ZA: just sitting, letting phenomena arise and pass, objectless concentration, not thinking.

2.3.3.5. Data Conditioning

Eye movement artifacts were corrected using independent component analysis. Then, all data were parsed into data epochs of 2 seconds. All data epochs were screened for artifacts by hand-and-eye on a PC display. Data epochs containing movement, sweat, muscle and technical artifacts were omitted. Up to 3 bad channels were replaced by the average of the direct neighbor channels. In the five groups, on average across participants, N/N channels were replaced: TB: 1.5/19, QG: 1.4/19, SY: 0.5/19, AY: 0.3/19, ZA: 1.0/58. If there were more than 3 bad channels, the subject was excluded (1 TB, 1 ZA). From all data sets, the 19 standard channels (Fp1/2, F7/8, F3/4, Fz, T3/4, C3/4, Cz, T5/6, P3/4, Pz, O1/2) of the international 10–20 system were selected for further analysis.

The artifact-free EEG data eventually available for analysis is listed in Table 2.

Table 2.
Artifact-free EEG data (s, mean and its standard error (SEM) across participants) eventually available for analysis.

	Initial rest		Meditation		Final rest	
	mean s	SEM s	mean s	SEM s	mean s	SEM s
Tibetan Buddhists	153.4	3.3	1116.0	55.4	139.8	9.9
QiGong	144.9	4.3	1006.8	45.7	141.7	2.5
Sahaja Yoga	142.7	4.9	1102.9	13.7	146.3	6.2
Ananda Marga Yoga	144.7	4.2	1041.9	36.9	153.0	2.1
Zen	120.2	2.3	1622.6	87.1	118.0	4.2

2.3.3.6. Coherence

2.3.3.6.1. Intracortical LORETA-based lagged coherence

All EEG data epochs were re-computed into cortical current density time series at 6239 cortical voxels using standardized Low Resolution Electromagnetic Tomography (sLORETA, Pascual-Marqui, 2002), available as free academic software package at <http://www.uzh.ch/keyinst/loreta.htm>.

The sLORETA method is a properly standardized discrete, linear, minimum norm, inverse solution that solves the problem to compute the three-dimensional cortical distribution of the electric neuronal source activity from the EEG measurements which are recorded on the head surface. The particular form of standardization used in sLORETA endows the tomography with the property of exact localization to test point sources, yielding images of standardized current density with exact localization, albeit with low spatial resolution (i.e. neighboring neuronal sources will be highly correlated). The detailed description of the method can be found in (Pascual-Marqui, 2002). The proof of its exact, zero-error localization property is given in (Pascual-Marqui, 2009), where it is also shown that sLORETA has no localization bias even in the presence of measurement and biological noise. In this sense, sLORETA is an improvement over the previously developed related tomography LORETA (Pascual-Marqui, 2002). Validation for sLORETA tomography mostly rests upon the abundant published validation for the previous LORETA method. For instance, excellent localization agreement has been reported in multimodal imaging studies with functional MRI (Mulert et al., 2004; Vitacco et al., 2002), structural MRI (Worrell et al., 2000), and PET (e.g. Dierks et al., 2000; Zumsteg et al., 2005). Further validation based on accepting as “ground truth” the information provided by intracranial recordings in humans has been reported in a number of papers (e.g. Yang et al., 2011; Zumsteg et al., 2006). Several recent papers also documented that sLORETA reveals valid results (e.g. Betting et al., 2010; Dümpelmann et al., in press; Laxton et al., 2010). Particularly noteworthy is a comparative validation study using intracranial recordings from epilepsy patients (Plummer et al., 2010) where they show that overall, sLORETA is the method with lowest localization error.

Regions of Interest (ROIs) are needed for the estimation of electric neuronal activity that is used to analyze brain functional connectivity. No general rules for constructing the ROIs are available. In order to assess functional connectivity between all major areas, the cortex areas under the 19 head surface electrode locations Fp1/2, F7/8, F3/4, Fz, C3/4, Cz, T3/T4, T5/6, P3/4, Pz, O1/2 of the international 10/20 system (Jasper, 1958) were used. The brain regions under these electrodes are tabulated in (Okamoto et al., 2004). A ROI was defined for the cortical voxels under each electrode, in such a way that all cortical voxels were assigned to the "origin" electrode to which they were closest. The signal at each cortical ROI consisted of the average electric neuronal activities of all voxels belonging to that ROI, as computed with sLORETA. Between the sLORETA current density time series of the 19 ROIs, intracortical 'lagged' coherence (Pascual-Marqui, 2007; Pascual- Marqui et al., 2011) was computed between all possible 171 pairs of the 19 ROIs for each of the eight independent EEG frequency bands (Kubicki et al., 1979; Niedermeyer and Lopes da Silva, 2005 p. 1234) of delta (1.5-6 Hz), theta (6.5-8 Hz), alpha-1 (8.5-10 Hz), alpha-2: (10.5-12 Hz), beta-1 (12.5-18 Hz), beta-2 (18.5-21 Hz), beta-3 (21.5-30 Hz), and additionally gamma (35–44 Hz) for each subject and for each condition. The well-known definition for the complex valued coherence (see e.g. Nolte et al., 2004) between time series x and y in the frequency band ω is:

Eq. 1 $$r_{xy\omega} = \frac{\operatorname{Re} Cov(x,y) + i \operatorname{Im} Cov(x,y)}{\sqrt{Var(x) \times Var(y)}}$$

which is based on the cross-spectrum given by the covariance and variances of the signals, and where i is the imaginary unit ($\sqrt{-1}$). The squared modulus of the coherence is:

Eq. 2 $$r^2_{xy\omega} = \frac{\left[\operatorname{Re} Cov(x,y)\right]^2 + \left[\operatorname{Im} Cov(x,y)\right]^2}{Var(x) \times Var(y)}$$

and the lagged coherence (Pascual-Marqui, 2007; Pascual-Marqui et al., 2011) is:

Eq. 3 $$LagR^2_{xy\omega} = \frac{\left[\operatorname{Im} Cov(x,y)\right]^2}{Var(x) \times Var(y) - \left[\operatorname{Re} Cov(x,y)\right]^2}$$

The lagged coherence was developed as a measure of true physiological connectivity not affected by volume conduction and low spatial resolution. It has been shown in Pascual-Marqui et al. (2011) to give an improved connectivity measure as compared to the imaginary coherence proposed by Nolte et al., (2004).

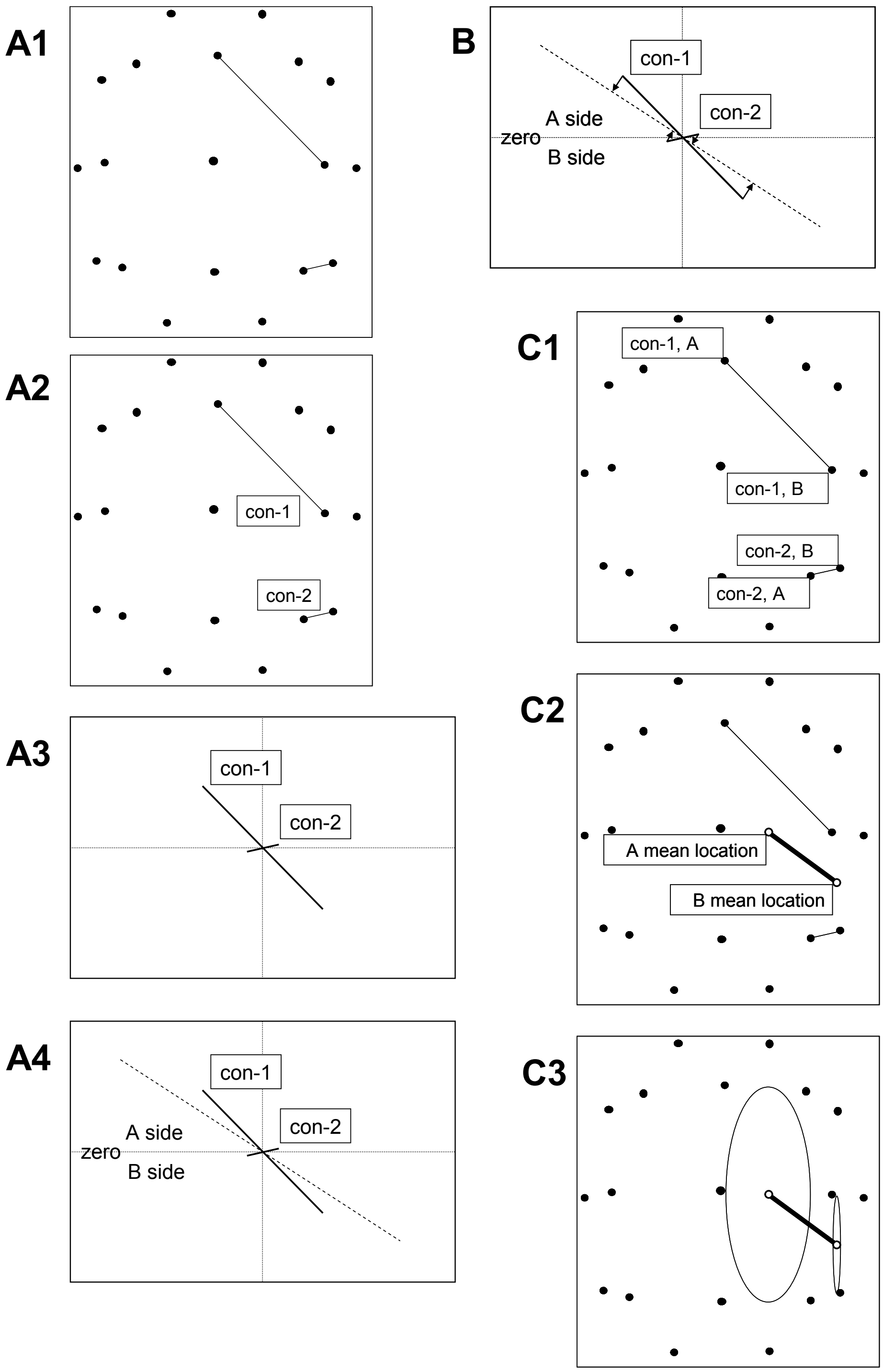

Fig. 1. Computation scheme of the ‘principal functional connectivity’. Head seen from above, nose up. A1, A2: ROIs shown as dots in glass brain view; presume there are two significant connectivities (con-1, con-2, shown as straight lines), each one joining two ROIs. A3: The connectivities were centered by subtracting for each pair of joined ROI locations the mean location of the pair. A4: Presume the first principal component computed in 3-dimensional space for the two participating location pairs (connectivities) yields the dashed straight line, corresponding to the principal direction of the connectivities. B: The significant connectivities are projected onto the principal component straight line and the locations are labeled as “A” (for the positive projection) and “B” (for the negative projection). C1: The labeled ROIs of the significant connectivities shown in the original space. C2: The original pair locations of the participating connectivities, now labeled as A and B, are separately averaged for A's and B's, giving the mean locations thus constituting a principal functional connectivity. C3: Mean locations and standard errors of the principal functional connectivity resulting from the two significant connectivities shown in A1.

2.3.3.6.2. Head surface EEG coherence

After re-computation of the EEG data to average reference, classical coherence (Eq. (2)) was computed between all possible 171 pairs of the 19 electrode locations for each of the eight independent EEG frequency bands (see preceding Section 2.6.1) for each subject and for each condition.

2.3.3.6.3. Statistical analysis of coherences

The intracortical lagged coherence results between the 19 ROIs, and the conventional EEG coherence results between the 19 head surface locations were analyzed as follows:

For each group of meditators and for each EEG frequency band, using paired t-statistics on the coherence values after Fisher's z transformation, the 171 possible coherences were compared between meditation versus initial rest as well as meditation versus final rest. Correction of significance for multiple testing applied the nonparametric randomization procedure (Nichols and Holmes, 2002) in the sLORETA program package. The correction was computed for the two comparisons between conditions for each frequency band for each group.

2.3.3.7. Topography of the principal functional connectivity

The major spatial tendency common to all significant functional connectivities (resulting from the comparisons between conditions) between the 19 ROIs of a given group, now called ‘principal functional connectivity’ was computed using principal component analysis as follows (see Fig. 1): All significant connectivities, i.e. connected pairs of original locations were centered to the origin of a 3-D space by subtracting for each pair the mean location of the pair (Fig. 1A). The first principal component was computed for all participating location pairs (connectivities) yielding a straight line in three-dimensional result space (Fig. 1A4). All connectivities were normalized to unity sphere. The two pair locations of each connectivity were orthogonally projected onto the principal component straight line (Fig. 1B). The projected location was labeled ‘A’ if the distance of the resulting point to the origin was positive and the corresponding location of the pair was labeled ‘B’. The original threedimensional pair locations of the participating connectivities, now labeled as A and B, were separately averaged for A's and B's into x, y, z mean locations (and standard errors) for each group, thus constituting a principal functional connectivity for a given group, for a given frequency band, and for a given comparison between conditions (Fig. 1C).

In a subsequent, second principal component analysis (done as above), the principal functional connectivities of the five groups were computed into a principal functional connectivity for a given frequency band and a given comparison between conditions.

A repeated measure ANOVA (2 comparisons between conditions×those frequency bands that yielded significant differences between conditions in all five groups×2 mean locations: A and B×3 brain axes: x, y, z) was done on the topographies of the principal functional connectivites of the five groups. All mean locations A and B of the principal functional connectivities were planned to be tested on the three brain axes for possible differences between the two comparisons between conditions.

2.3.3.8. Power spectra

Power spectra were computed from the head surface EEG data versus average reference using an FFT routine with box-car windowing. The spectra were subject-wise normalized (‘relative power’) and averaged across the 19 channels for each subject and condition. Integrated values were computed for the eight independent frequency bands of delta through gamma (see Section 2.6.1. above).

2.3.4. Results

2.3.4.1. Lagged coherence between intracortical ROIs

Lagged intracortical coherences that differed at $p<0.05$ after correction for multiple testing between meditation and initial rest or between meditation and final rest were identified. The t-values accepted at $p<0.05$ after correction for multiple testing ranged from 4.811 to 5.383. All significant differences of lagged intracortical coherence between conditions concerned lower values during meditation than initial or final rest, i.e., none of the tests reached significance for higher values during meditation than initial or final rest in any frequency band. The total number of significant cases in all eight frequency bands in the five groups were: 49 for TB, 138 for QG, 106 for SY, 33 for AY and 33 for ZA, respectively. The five groups markedly differed in the number of significant cases in given frequency bands (Fig. 2A and B).

We note that for the comparison between initial rest versus meditation (Fig. 2A) as well as for the comparison between final rest versus meditation (Fig. 2B), the two frequency bands of delta and beta-2 showed one or more than one significant difference in all five groups. On the other hand, Fig. 2C shows that the results differed somewhat between initial rest versus meditation and final rest versus meditation. This latter Figure also shows that the greatest numbers of significantly lower lagged intracortical coherence during meditation, comparing both initial rest versus meditation as well as final rest versus meditation, were observed for the frequency bands of delta and beta-2. Fig. 2D displays the grand means across groups and comparisons for each frequency band of the number of tests that were significant after correction for multiple testing; the standard error bars show a relatively large variance across groups in the delta band and a small variance in the beta-2 band.

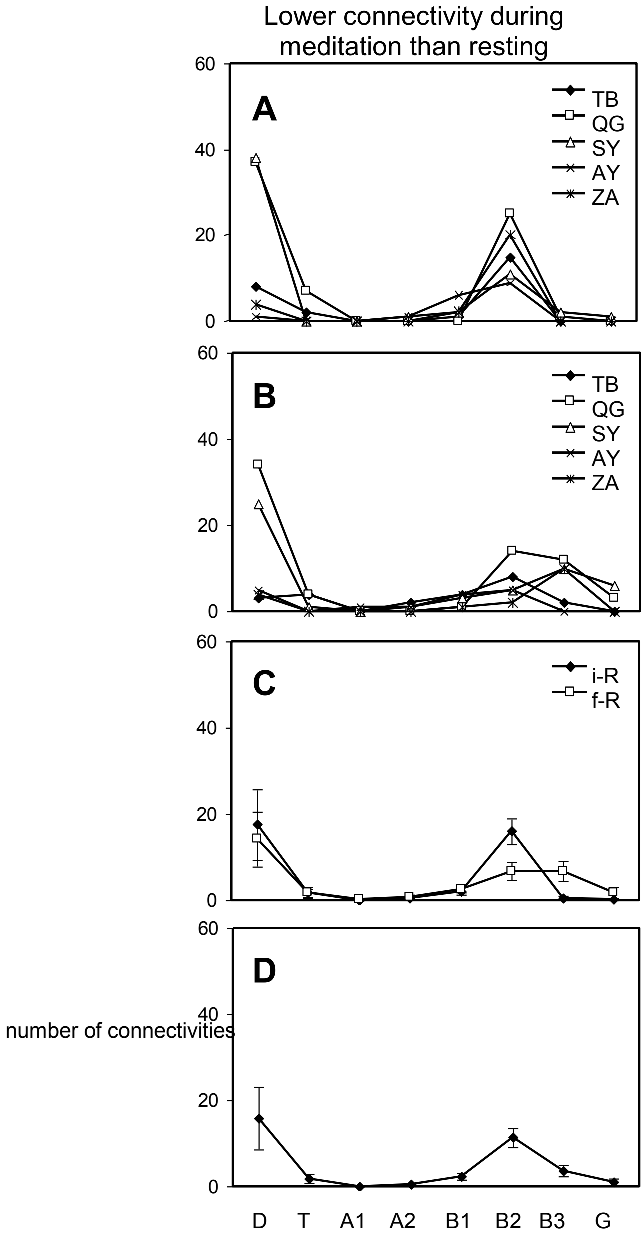

Fig. 2. Numbers of connectivities between intracortical ROI's (assessed with intracortical lagged sLORETA-based coherence) that differed significantly between meditation and rest after correction for multiple testing. Note that all significant cases had lower coherence during meditation than rest, i.e. there was no significantly different case with higher intracortical lagged coherence during meditation than rest. A: Initial rest versus meditation, and B: final rest versus meditation, displaying the total number of significant cases for each of the five groups. C: Mean number of significant cases (and S.E.) across the five groups for meditation versus initial rest (i-R) and meditation versus final rest (f-R). - D: Grand mean number of significant cases (and standard error) across the five groups, for meditation versus mean of initial and final rest. - EEG frequency bands: D=delta; T=theta; A=alpha; B=beta; G=gamma.

2.3.4.2. Topography of the principal functional connectivity between intracortical ROIs

To test the topography of the connectivities for common tendencies across groups, the results of the delta and beta-2 frequency band were suitable since all five groups are represented with significant results in these two frequency bands. The connectivities that after correction for multiple testing significantly differed between conditions in the delta and beta-2 frequency bands are illustrated in Fig. 3 which shows the concerned connections between the 19 ROIs in glass brain view seen from above. In some cases where there are not too many connections, a predominant topography can be gleaned from examining the display. For example, in the delta band, visual inspection suggests that in the comparison of final rest versus meditation (Fig. 3, Delta f-R) there is a general tendency for left to right oriented connections in posterior regions in the TB group, and a general tendency to anterior left to more posterior right-oriented connections in the AY group. When many connections are involved as e.g. in the QG group, such guesses evidently become impossible.

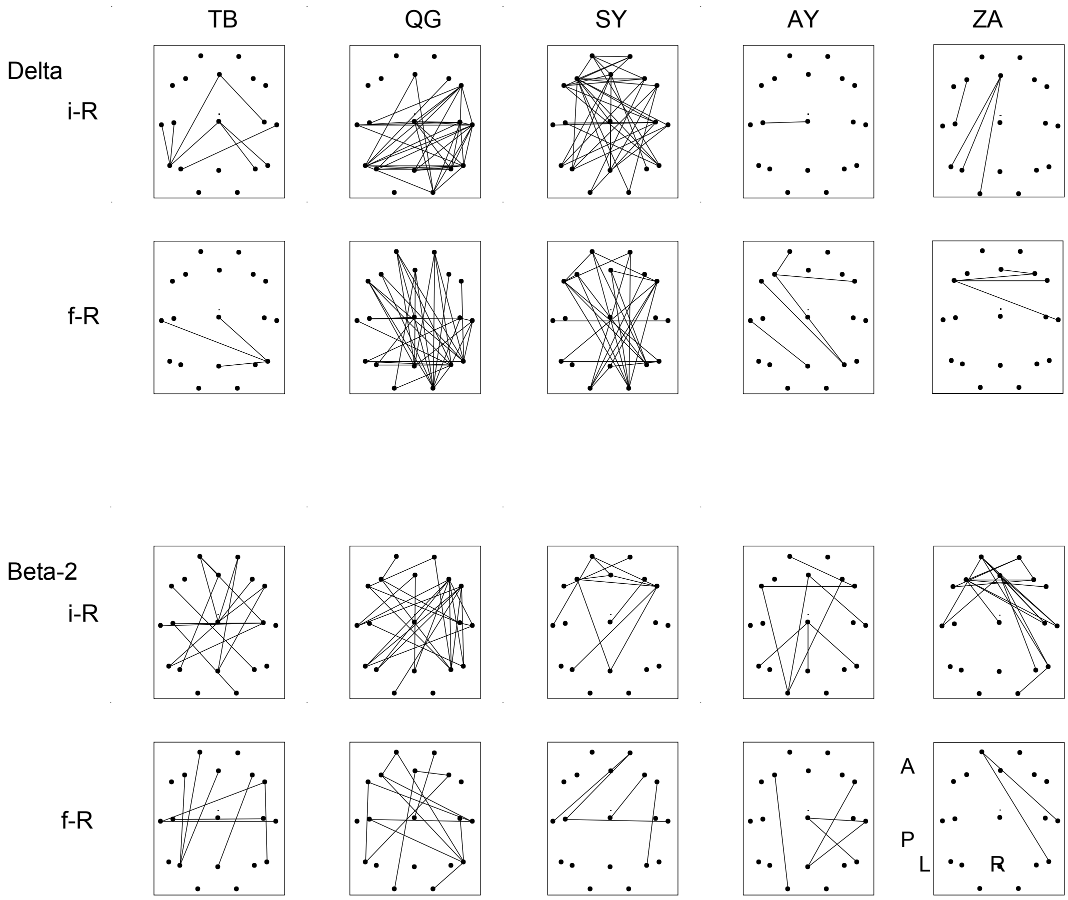

Fig. 3. Glass brain views of connectivities (in the delta and beta-2 frequency bands) that were significantly different (corrected for multiple testing) between initial rest (i-R) versus meditation, and final rest (f-R) versus meditation, in the 5 groups. Note that all significant connectivities were lower in meditation than rest. TB: Tibetan Buddhists, QG: QiGong, SY: Sahaja Yoga, AY: Ananda Marga Yoga, ZA: Zen. The 19 ROIs are indicated by dots. Head seen from above, nose up. A: anterior, P: posterior, L: left, R: right.

The computation of the topography of the principal functional connectivity allows further evaluation without subjective decisions. The principal functional connectivities obtained from the connectivites of Fig. 3 are displayed in Fig. 4. Inspection of these results suggests in turn that in both frequency bands, the principal functional connectivities differ between intial rest versus meditation and final rest versus meditation, and differ between groups for a given comparison.

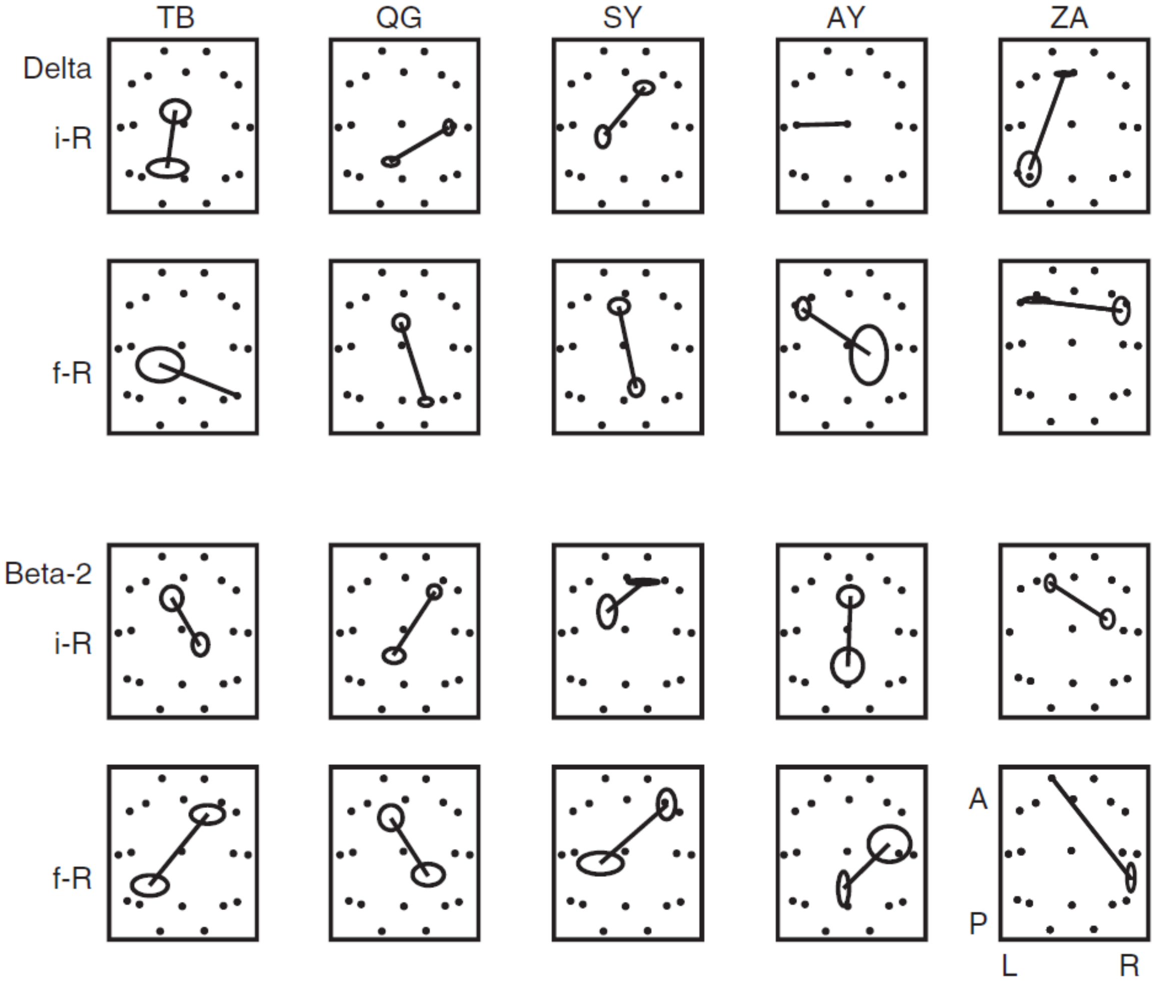

Fig. 4. Glass brain views of principal functional connectivities computed from the results in Fig. 3 for each of the five groups. The mean locations of the principal functional connectivities and their standard error (round shapes) of the means across the five groups are displayed. TB: Tibetan Buddhists, QG: QiGong, SY: Sahaja Yoga, AY: Ananda Marga Yoga, ZA: Zen. i-R: Meditation versus initial rest; f-R: Meditation versus final rest. The 19 ROIs are indicated by dots. Head seen from above, nose up. A: anterior, P: posterior, L: left, R: right.

The computation of principal functional connectivity across the results of the five groups that were shown in Fig. 4 indeed demonstrates that in the delta frequency band (Fig. 5A), initial rest versus meditation showed decreased connectivity between right anterior and left posterior regions, while final rest versus meditation showed decreased connectivity between left anterior and right posterior regions. In the beta-2 frequency band (Fig. 5B), on the other hand, the differences between the principal functional connectivities of initial rest versus meditation and final rest versus meditation are small, both principal functional connectivities being midline-near and oriented anterior-posterior.

The repeated measure ANOVA (2 comparisons x 2 frequency bands x 2 mean locations x 3 brain axes) of the five groups' data in Fig. 5 yielded a significant interaction (comparisons x frequency bands x mean locations x axes) at F(2,8)=12.31, p=0.0036. Separate follow-up ANOVAs for the two frequency bands showed a significant interaction (comparisons x mean locations x axes) for the delta band (F(2,8)=9.34, p=0.0080) and a trend interaction for the beta-2 band (F(2,8)=3.12, p=0.0998).

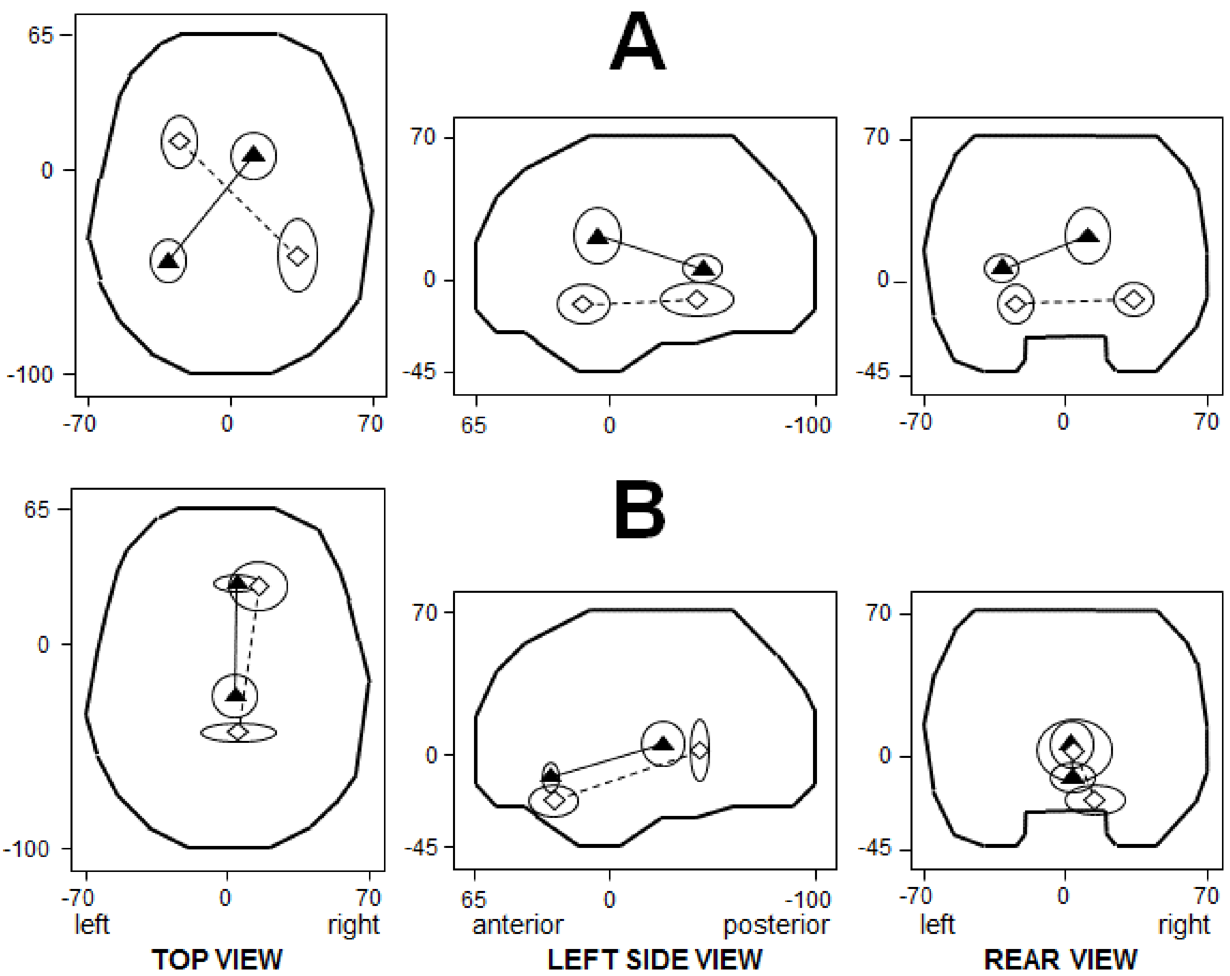

Fig. 5. Principal functional connectivities in the delta (A) and beta-2 (B) frequency band. Means (symbols) and standard errors of the mean localizations (round shapes) of the principal functional connectivities of decreased lagged intracortical coherence across the five groups. Black triangles: initial rest versus meditation; Open diamonds: final rest versus meditation. Glass brain views. Axis scales correspond to millimeters in the digitized Talairach atlas from the Montreal Neurological Institute. Note the small variance of the mean localizations across groups.

The principal functional connectivities of the two comparisons 'initial rest versus meditation' and 'final rest versus meditation' in the delta band (Fig. 5A) showed the following significant topographic differences in the planned least significant difference tests of the data of the five groups: On the left-right axis, the anterior mean locations of the two principal functional connectivities differed at p=0.03 and the posterior mean locations differed at p=0.0002. On the anterior-posterior axis, the left mean locations of the two principal functional connectivities differed at $p=0.001$ and the right mean locations differed at $p=0.004$. On the inferior-superior axis, the anterior mean locations of the two principal functional connectivities differed at $p=0.08$.

2.3.4.3. Coherence between head surface locations

Of the total of 13680 tests (2 comparisons between conditions, 5 groups, 8 frequency bands, 171 coherences per frequency band) for differences between conditions using head surface EEG coherences, only 72 tests were significant after correction for multiple testing; of these, 3 had higher, 69 lower coherences during meditation than rest. ZA cases outnumbered the other four groups: 64 ZA cases versus a total of 8 for the other four groups.

This contrasts starkly with the results for differences between conditions using lagged intracortical coherence, where 359 of the 13680 tests were significant after correction for multiple testing and where, as reported above, all of them revealed lower values, none of them higher values during meditation than rest.

The extremely small number of significant differences in conventional EEG coherence between head surface locations after correction for multiple testing in the four groups LA, QG, SY and AY precluded comparisons with lagged intracortical coherences. In order to meaningfully compare the two analysis approaches, we therefore examined differences of coherence between conditions that reached $p<0.05$ without correction for multiple testing.

Conventional head surface EEG coherence (Fig. 6) clearly showed much greater numbers of lower than higher coherence during meditation compared to rest, initial as well as final. But, there were also notable differences between groups where for example SY and ZA showed more increases than decreases in the theta band for the comparison of initial resting versus meditation (Fig. 6A and B). Across the five groups, the smallest number of lower coherences during meditation versus rest occurred in the theta frequency band (Fig. 6C and D).

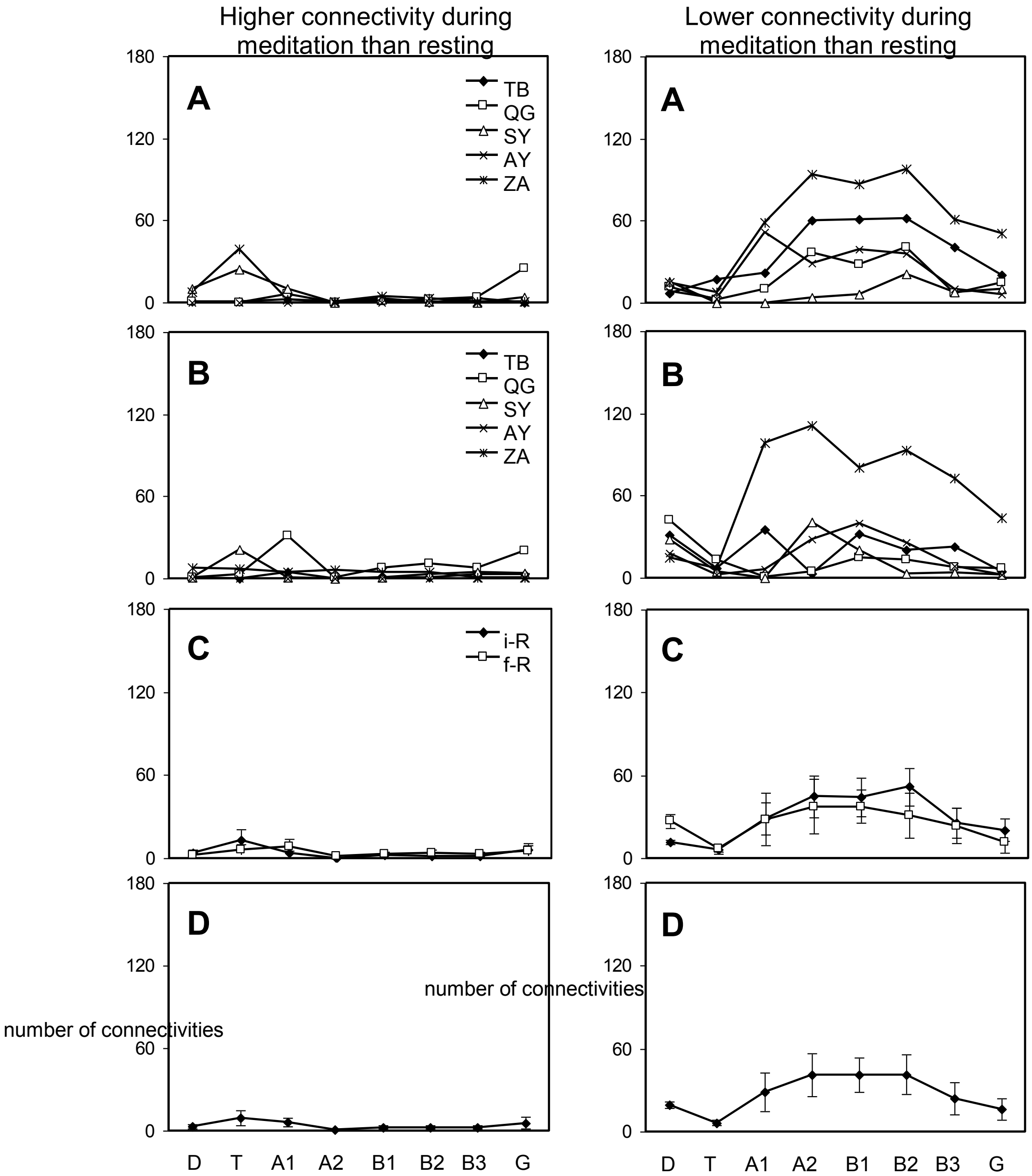

Fig. 6. Number of head surface EEG connectivities between electrode positions that changed in intensity at p(uncorrected)<0.05 between initial rest versus meditation and final rest versus meditation. Left: cases of increased connectivities; Right: cases of decreased connectivities. A: Number of connectivities in each of the five groups, initial rest versus meditation. B: Number of connectivities in each of the five groups, final rest versus meditation. C: Mean across groups, initial rest versus meditation (solid symbols) and final rest versus meditation (open symbols), and standard errors of the means. D: Grand mean (and standard error) across the five groups (mean of initial and final rest versus meditation). - EEG frequency bands: D=delta; T=theta; A=alpha; B=beta; G=gamma.

Lagged intracortical coherence, on the other hand, at uncorrected $p<0.05$ still yielded only 2 cases of higher coherence during meditation than rest (Fig. 7), but extremely great numbers of coherences lower during meditation than rest, up to 170 of the possible 171 cases per group, comparison and frequency band, particularly great for delta and beta-2 frequencies (Fig. 7A and B). Fig. 7C and D show that the five traditions displayed some agreement, with the greatest numbers of lower coherences during meditation than rest in the delta and beta-2 frequency band, and the smallest numbers in the alpha-1 band. This latter observation is in contrast to the head surface EEG coherence results of Fig. 6 where the theta band showed the smallest mean number across groups of lower coherences during meditation than rest.

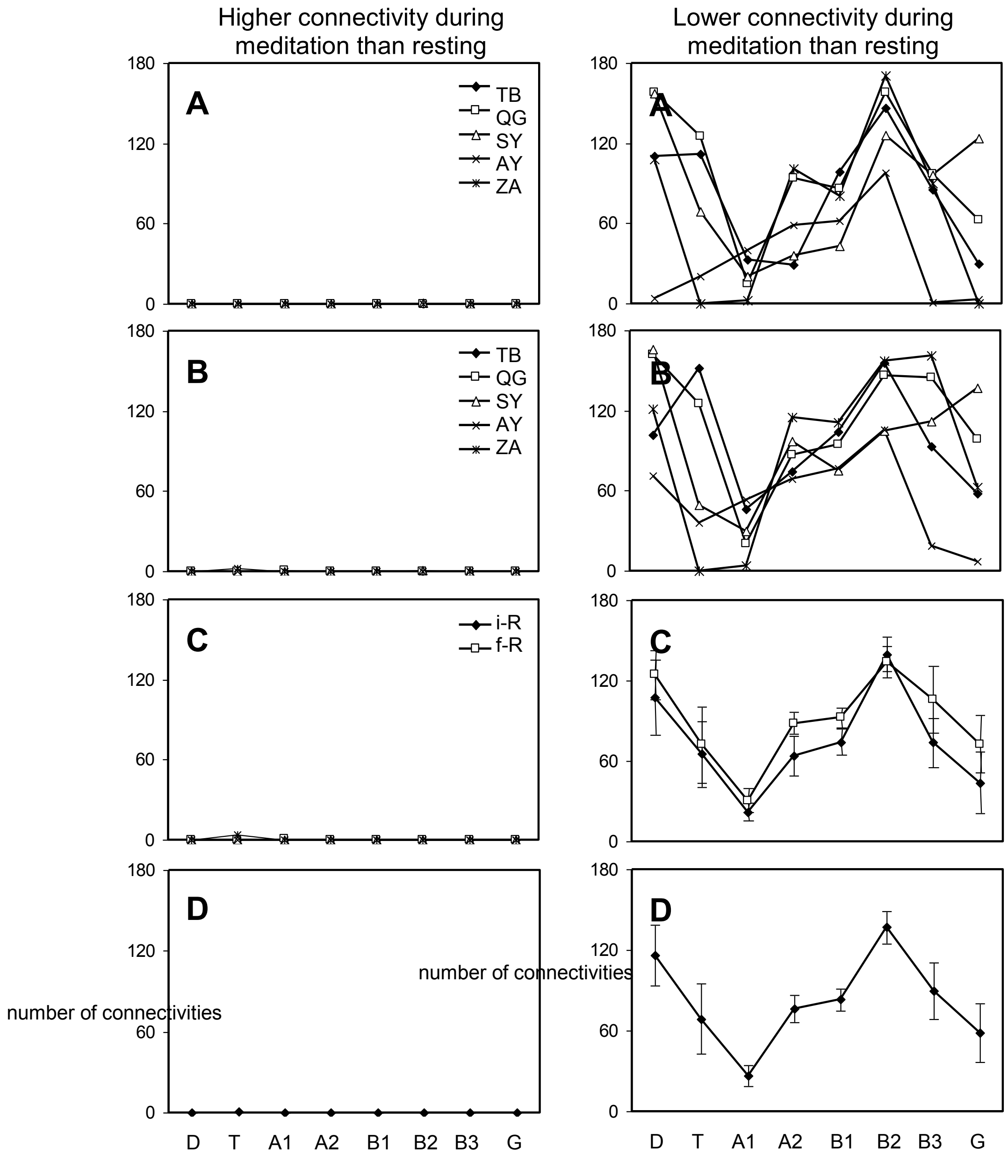

Fig. 7. Number of lagged intracortical connectivities between ROIs that changed in intensity at p(uncorrected)<0.05 between initial rest versus meditation and final rest versus meditation. Left: cases of increased connectivities; Right: cases of decreased connectivities. A: Number of connectivities in each of the five groups, initial rest versus meditation. B: Number of connectivities in each of the five groups, final rest versus meditation. C: Mean across groups, initial rest versus meditation (solid symbols) and final rest versus meditation (open symbols), and standard errors of the means. D: Grand mean (and standard error) across the five groups (mean of initial and final rest versus meditation). - EEG frequency bands: D=delta; T=theta; A=alpha; B=beta; G=gamma.

3.3.4.4. The magnitude of coherence values

The mean values of all lagged intracortical coherences across the five groups and the three conditions are illustrated in Fig. 8A. Delta, beta-3 and gamma band mean values were very low (r=0.02), while the two alpha bands had the highest mean values (r=0.21, 0.18, respectively). Comparable distributions occurred in the three conditions (Fig. 8B and C).

The coherence values during rest compared to meditation showed very large differences in some frequency bands, during rest up to 172% of the meditation value (Table 3).

The mean values of lagged intracortical coherence were between 9% (for delta) and 50% (for alpha-1) of the mean values for head surface EEG coherence (Fig. 8A).

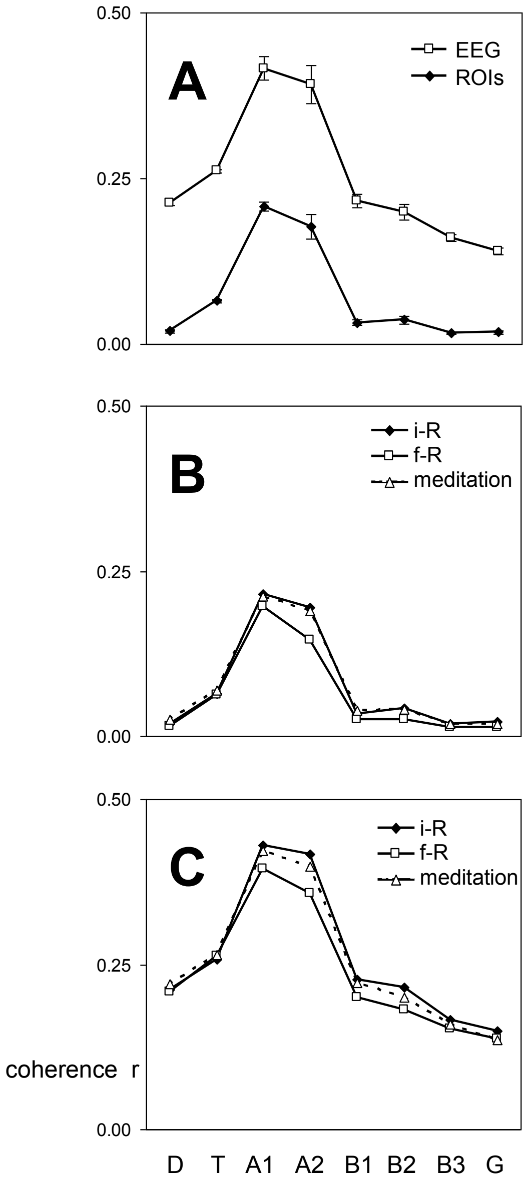

Fig. 8. A: Mean values of coherence and standard error of the mean across the five groups in the eight EEG frequency bands. ROIs: lagged intracortical coherence between ROIs; EEG: head surface EEG coherence. - B: Lagged intracortical coherence between ROIs, and C: Head surface EEG coherence values, averaged across groups. i-R: initial rest; f-R: final rest; meditation. - EEG frequency bands: D=delta; T=theta; A=alpha; B=beta; G=gamma.

2.3.4.5. Power spectra

The five groups displayed drastic differences in relative power from each other, but with comparable patterns for initial (Fig. 9A) and final rest (Fig. 9B) compared to meditation, i.e. mean results across groups for initial and for final rest compared to meditation were quite comparable, showing lower values in the alpha-2 frequency band, and higher values in the beta-3 and gamma band (Fig. 9C). During meditation compared to resting, the grand mean values across groups were significantly lowered in the alpha-2 frequency band, and showed a tendency to higher values in the beta-3 and gamma band (Fig. 9D).

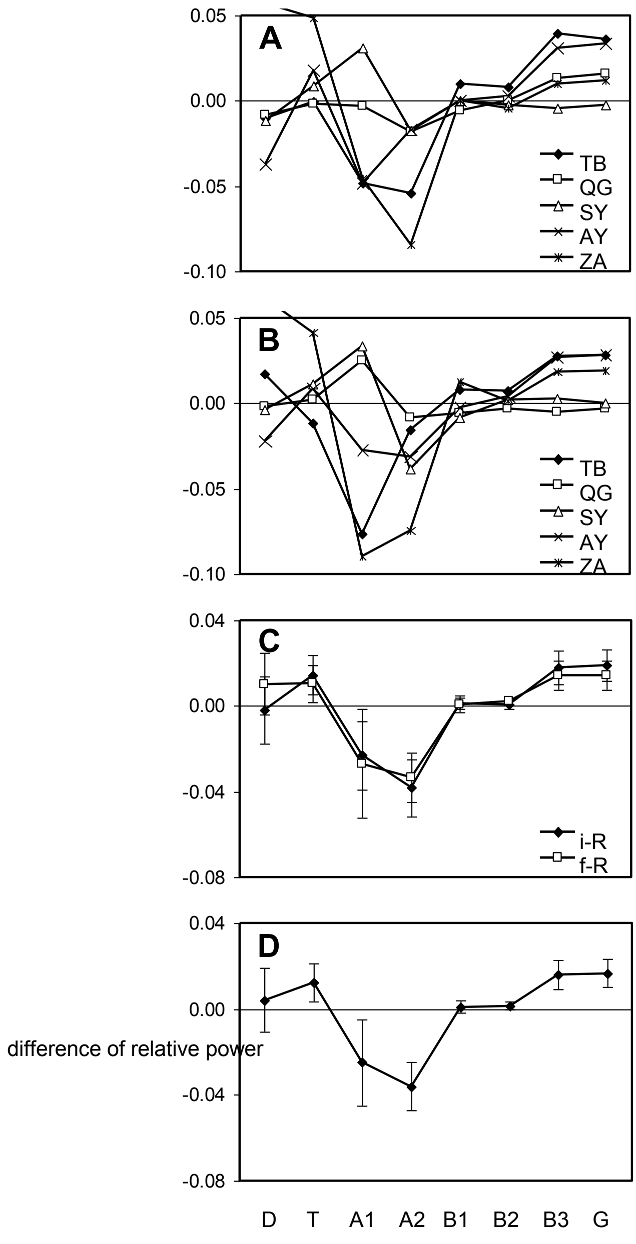

Fig. 9. A: Mean differences of relative power during meditation minus initial rest of the five groups. B: Mean differences of relative power during meditation minus final rest of the five groups. C: Mean differences of relative power across groups and standard error of the mean during meditation minus initial rest (closed symbols) and during meditation minus final rest (open symbols). D: Grand mean differences of relative power across groups (and

standard error) during meditation minus mean rest in the eight EEG frequency bands. - EEG frequency bands: D=delta; T=theta; A=alpha; B=beta; G=gamma.

Table 3.
Mean coherence values across groups during the two rest conditions expressed as percentages of the values during meditation, and mean coherence values and their standard error (SEM) during the three conditions, for the eight frequency bands.

	Coherence during initial rest referred to meditation %	Coherence during final rest referred to meditation %	Mean coherence (r) across the 5 groups: initial rest r	meditation r	final rest r	initial rest r SEM	meditation r SEM	final rest r SEM
Cortical source regions of interest, lagged coherence								
delta	128	162	0.019	0.015	0.025	0.001	0.004	0.004
theta	102	112	0.064	0.062	0.070	0.006	0.010	0.005
alpha1	109	108	0.215	0.196	0.212	0.047	0.049	0.035
alpha2	134	131	0.194	0.146	0.190	0.037	0.035	0.035
beta1	136	150	0.035	0.025	0.038	0.005	0.004	0.005
beta2	172	162	0.043	0.025	0.041	0.003	0.004	0.002
beta3	150	149	0.019	0.013	0.019	0.003	0.003	0.002
gamma	158	126	0.023	0.014	0.018	0.004	0.003	0.003
Head surface data, conventional coherence								
delta	102	106	0.212	0.208	0.221	0.007	0.005	0.006
theta	98	101	0.257	0.262	0.265	0.007	0.012	0.008
alpha1	109	107	0.431	0.395	0.423	0.037	0.043	0.030
alpha2	117	111	0.418	0.358	0.398	0.034	0.038	0.036
beta1	113	110	0.227	0.201	0.222	0.011	0.015	0.008
beta2	119	111	0.216	0.182	0.201	0.010	0.011	0.009
beta3	109	105	0.167	0.152	0.160	0.003	0.008	0.005
gamma	109	100	0.149	0.137	0.136	0.004	0.013	0.005

2.3.5. Discussion

In meditators of five different traditions, the functional connectivity between brain regions coherence was significantly (corrected for multiple testing) lower during meditation compared to rest before meditation as well as compared to rest after meditation. There was not a single case of higher coherence during meditation than rest in any of the five groups and any of the eight frequency bands. This main result was obtained with an analysis strategy (lagged intracortical coherence) that used EEG source modeling to exclude ambiguity of localization and reference-dependence, and that omitted zero phase angle coherences to avoid undue inflation of coherence by volume conduction. Conventional head surface EEG coherence of our dataset also yielded a remarkable predominance of decreased coherence. But, there was also some increased coherence during meditation compared to initial rest (before meditation) and final rest (after meditation).

The reduction of lagged intracortical coherence during meditation was observed in all eight EEG frequency bands, hence similarly concerned inhibitory and excitatory brain functions, e.g. delta and beta frequencies, respectively (Niedermeyer and Lopes da Silva, 2005).

Increase of head surface EEG coherence reportedly is associated with successful task performance (e.g. Anokhin et al., 1999; Beaumont et al., 1978; Holz et al., 2008; Okuhata et al., 2009;Weiss et al., 2005), but also, increased coherence has been reported during sleep compared to wakefulness (e.g. Dumermuth et al., 1983; Kaminski et al., 1997; Nielsen et al., 1990). Thus, the global decrease of coherence during meditation in all our five groups suggests that meditation is not simply comparable to task execution or sleep. We note that neither increase nor decrease of EEG coherence is a virtue in itself; general high coherence is observed during epileptic seizures (e.g. Milton and Jung, 2003) while decreased coherence is observed during schizophrenic symptomatology (e.g. Pascual-Marqui et al., 2011).

Since coherence assesses the cooperativity between system units, lower coherence implies higher functional independence of the system units. Thus, such a finding is expected to result in higher measures of dimensionality. In fact, in a pilot study where we computed Omega dimensionality (Wackermann, 1996, 1999) of our dataset (Faber et al., 2011), three of the five groups showed significant differences between meditation and rest, with higher dimensionality during meditation.

Papers on EEG coherence during meditation analyzed head surface data that in our study showed not only decreased but also increased connectivities. Increased head surface coherence during Transcendental Meditation (TM) has been reported repeatedly as reviewed in the introduction. Unfortunately, our data do not include TM practitioners. Unlike the five traditions in our study, instructions for TM discourage attention to body sensations such as e.g. attention to one's own breathing. We note, however, that one of our groups (QG) also showed increased head surface alpha-1 coherence. Increased head surface alpha coherence was also observed in Zen meditation, but in novices where it is questionable whether they reached optimal states in view of their lack of experience (Murata et al., 2004). Our experienced ZA group did not show increased alpha coherence. The reported increased head surface theta coherence in Sahaja Yoga meditators (Aftanas and Golocheikine, 2001) was also observed in our Sahaja Yoga group (Fig. 6). The increased head surface gamma frequency band phase locking observed in Buddhist meditators (Lutz et al., 2004) suggested increased connectivity; however, our corresponding group of Buddhist meditators generally showed more decreases than increases of head surface EEG coherence during meditation, including the gamma band. Because of the caveats on head surface EEG coherence reviewed in the introduction, conclusions about true functional connectivity remain ambiguous.

Therefore, the present study centered on functional connectivity as measured with intracortical lagged coherence; this approach revealed quite similar results in the five examined, different meditation traditions. We are aware that in other EEG measurements, different meditation techniques are known to show different characteristics (e.g. Dunn et al., 1999; Lehmann et al., 2001; Lutz et al., 2008; Travis, 2001; Travis and Shear, 2010). Also within the framework of the present analysis, the five groups showed clear differences in the frequency of cases of significantly decreased connectivities (Fig. 2A and B). However, the present study did not analyze other specific differences between groups. Our present results demonstrate a major commonality across the five analyzed groups which differed to some extent in practices and experience: In all five separately analyzed groups, intracerebral source model connectivity was lower during meditation than during resting before and after meditation, with relatively small variance of the grand means across groups. Low variance across groups was also evident in the topography of the principal functional connectivities between intracortical ROIs.

Going into and coming out of meditation was associated with different changes of coherence topography in the delta frequency band: In other words, going out of meditation into final rest (after meditation) did not simply reverse the coherence decrease that was observed comparing initial rest (before meditation) with meditation. Thus, the brain breaks up into more independent behavior when going into meditation, and rewires itself when leaving meditation, but via a different route. This is not surprising since one could reasonably expect some temporarily persisting effect of meditation (see also Northoff et al., 2010 on pre-task and post-task resting). Indeed, even long-term electro-physiological effects of meditation are known (Davidson et al., 2003; Lutz et al., 2004; Tei et al., 2009). But, the dissimilarity of the 'into' and 'out of' changes of connectivity was surprising: The topographies of the two principal connectivities were about orthogonal to each other. When going into meditation, there was a diagonally oriented right anterior to left posterior decrease of connectivity; coming out of meditation, there was also a diagonally oriented but crossed increase of connectivity oriented left anterior to right posterior. On the other hand, the beta-2 frequency band largely showed a reversal of connectivities: both the in- and out-topographies of the principal connectivities were midline-near, and anterior-posterior oriented, showing only small location differences. The remarkable diagonal orientation of the delta band principal connectivities is reminiscent of the observation that no-task resting EEG activity when clustered into four classes of spatial configurations of the brain electric field yields two classes with clearly diagonal oriented brain electric axes that cover about 50% of the total analysis time (Britz et al., 2010; Koenig et al., 2002).

The results of our study show, in sum, that functional interdependence between brain regions is globally reduced in optimal meditation states, regardless of the followed specific meditation practices, and that this reduction concerns inhibitory as well as excitatory brain activities. This increased functional independence – the decreased cooperativity - of brain processes suggests that experiences are handled more independently and influence less each other and the self process with its conscious experience. The self process comprises functions such as self awareness, autobiographic memory, agency, and embodiment (see e.g. Blanke and Arzy, 2005; Conway, 2005; Esslen et al., 2008; Farrer and Frith, 2002; Jantz and Beringer, 1944; James, 1890).

How may the observed general reduction of functional connectivity explain the major subjective experiences during meditation: On one hand the non-involvement of the self in momentary thoughts or percepts, and on the other hand the expansion of self consciousness (Cahn and Polich, 2006)? We propose the following speculative explanation: Because of the reduced internal connectivity of the functions of the self process, their processing of information coming from other processes is curtailed; this leads to a subjective experience which is described for example as non-involvement, detachment, and letting go. On the other hand, because the diminution of information handling within the self process progressively deprives the self process of constraining information about external and internal realities, this leads to a subjective experience which is described for example as expansion of consciousness, dissolution of ego borders, and all-oneness. Future work will have to examine possible specifics of these theories.

2.3.6. Acknowledgments

The authors thank Prof. Hiroaki Kumano for helpful discussions and Marlene E. Steiner, M.A. for work in data collection. Supported in part by Grant Nr. 44/06 from the Bial Foundation, S. Mamede do Coronado, Portugal.

2.3.7. References

Aftanas, L.I., Golocheikine, S.A., 2001. Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. Neurosci. Lett. 310, 57-60.

Anokhin, A.P., Lutzenberger, W., Birbaumer, N., 1999. Spatiotemporal organization of brain dynamics and intelligence: an EEG study in adolescents. Int. J. Psychophysiol. 33, 259-273.

Beaumont, J.G., Mayes, A.R., Rugg, M.D., 1978. Asymmetry in EEG alpha coherence and power: effects of task and sex. Electroenceph. Clin. Neurophysiol. 45, 393-401.

Betting, L.E., Li, L.M., Lopes-Cendes, I., Guerreiro, M.M., Guerreiro, C.A., Cendes, F., 2010. Correlation Between Quantitative EEG and MRI in Idiopathic Generalized Epilepsy. Hum. Brain Mapp. 31, 1327–1338.

Blanke, O., Arzy, S., 2005. The out-of-body experience: disturbed self-processing at the temporo-parietal junction. Neuroscientist 11(1), 16-24.

Brewer, J.A., Worhunsky, P.D., Gray, J.R., Tang, Y.Y., Weber, J., Kober, H., (in press). Meditation experience is associated with differences in default mode network activity and connectivity. Proc. Natl. Acad. Sci. USA.

Britz, J., Van De Ville, D., Michel, C.M., 2010. BOLD correlates of EEG topography reveal rapid resting-state network dynamics. NeuroImage 52, 1162-1170.

Burgess, A.P., Ali, L., 2002. Functional connectivity of gamma EEG activity is modulated at low frequency during conscious recollection. Int. J. Psychophysiol. 46, 91-100.

Cahn, B.R., Polich, J., 2006. Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychol. Bull. 132, 180-211.

Conway, M.A., 2005. Memory and the self. J. Mem. Lang. 53(4), 594–628.

Davidson, R.J., Kabat-Zinn, J., Schumacher, J., Rosenkranz, M., Muller, D., Santorelli, S.F., Urbanowski, F., Harrington, A., Bonus, K., Sheridan, J.F., 2003. Alterations in brain and immune function produced by mindfulness meditation. Psychosom. Med. 65, 564–570.

Dierks, T., Jelic, V., Pascual-Marqui, R.D., Wahlund, L.O., Julin, P., Linden, D.E.J., Maurer, K., Winblad, B., Nordberg, A., 2000. Spatial pattern of cerebral glucose metabolism (PET) correlates with localization of intracerebral EEG-generators in Alzheimer's disease. Clin. Neurophysiol. 111, 1817-1824.

Dillbeck, M.C., Bronson, E.C., 1981. Short-term longitudinal effects of the Transcendental Meditation technique on EEG power and coherence. Int. J. Neurosci. 14, 20-29.

Dumermuth, G., Lange, B., Lehmann, D., Meier, C.A., Dinkelmann, R., Molinari, L., 1983. Spectral analysis of all-night sleep in healthy adults. Europ. Neurol. 22, 322-339.

Dümpelmann, M., Ball, T., Schulze-Bonhage, A., in press. sLORETA allows reliable distributed source reconstruction based on subdural strip and grid recordings. Hum. Brain. Mapp.

Dunn, B.R., Hartigan, J.A., Mikulas, W.L., 1999. Concentration and mindfulness meditations: unique forms of consciousness? Appl. Psychophysiol. Biofeedback 24, 147-165.

Esslen, M., Metzler, S., Pascual-Marqui, R., Jancke, L., 2008. Pre-reflective and reflective self-reference: a spatiotemporal EEG analysis. NeuroImage 42(1), 437-449.

Faber, P.L., Lehmann, D., Milz, P., Tei, S., Kochi, K., 2011. Multichannel EEG dimensionality (Omega Complexity) during meditation in five meditation traditions. 31st Ann. Meeting, Swiss Society for Biological Psychiatry, Lausanne, Jan. 28, 2011. Abstract D2 in Abstract Book, p. 50.

Farrer, C., Frith, C.D., 2002. Experiencing oneself vs another person as being the cause of an action: the neural correlates of the experience of agency. NeuroImage 15(3),596-603.

Fischer, R., 1971. A cartography of the ecstatic and meditative states. Science 174(12), 897-904.

Gaylord, C., Orme-Johnson, D., Travis, F., 1989. The effects of the transcendental mediation technique and progressive muscle relaxation on EEG coherence, stress reactivity, and mental health in black adults. Int. J. Neurosci. 46, 77-86.

Goleman, D.J., 1996. The Meditative Mind: Varieties of Meditative Experience. Penguin Putnam, New York.

Hinterberger, T., Kamei, T., Walach, H., 2011. Psychophysiological classification and staging of mental states during meditative practice. Biomed. Tech. (Berlin) [Epub ahead of print].

Holz, E.M., Doppelmayr, M., Klimesch, W., Sauseng, P., 2008. EEG correlates of action observation in humans. Brain Topography 21, 93-99.

Jantz, H., Beringer, K., 1944. Das Syndrom des Schwebeerlebnisses unmittelbar nach Kopfverletzungen. Nervenarzt, 17, 197-206.

James, W., 1890. The Principles of Psychology, vol. 1. Holt, New York.

Jasper, H.H., 1958. The ten-twenty electrode system of the International Federation. Electroenceph. Clin.

Neurophysiol. 10, 371–375.

Kabat-Zinn, J., 1982. An outpatient program in behavioral medicine for chronic pain patients based on the practice of mindfulness meditation: theoretical considerations and preliminary results. Gen. Hosp. Psychiatry 4(1), 33-47.

Kabat-Zinn, J., 1990. Full Catastrophe Living: Using the Wisdom of Your Body and Mind to Face Stress, Pain, and Illness. Dell, New York.

Kaminski, M., Blinowska, K., Szelenberger, W., 1997. Topographic analysis of coherence and propagation of EEG activity during sleep and wakefulness. Electroenceph. Clin. Neurophysiol. 102, 216-227.

Koenig, T., Prichep, L., Lehmann, D., Sosa, P.V., Braeker, E., Kleinlogel, H., Isenhart, R., John, E.R., 2002. Millisecond by millisecond, year by year: normative EEG microstates and developmental stages. NeuroImage 16, 41-48.

Kubicki, S., Herrmann, W.M., Fichte, K., Freund, G., 1979. Reflections on the topics: EEG frequency bands and regulation of vigilance. Pharmakopsychiatr. Neuropsychopharmakol. 12, 237-245.

Laxton, A.W., Tang-Wai, D.F., McAndrews, M.P., Zumsteg, D., Wennberg, R., Keren, R., Wherrett, J., Naglie, G., Hamani, C., Smith, G.S., Lozano, A.M., 2010. A phase I trial of deep brain stimulation of memory circuits in Alzheimer's disease. Ann. Neurol. 68(4), 521-534.

Lehmann, D., Faber, P.L., Achermann, P., Jeanmonod, D., Gianotti, L.R.R., Pizzagalli, D., 2001. Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. Psychiatry Res.: Neuroimaging 108, 111-121.

Lehmann, D., Faber, P.L., Gianotti, L.L.R., Kochi, K., Pascual-Marqui, R.D., 2006. Coherence and phase locking in the scalp EEG and between LORETA model sources, and microstates as putative mechanisms of brain temporo-spatial functional organization. J. Physiol. (Paris) 99, 29–36.

Levine, P.H., 1976. The coherence spectral array (COSPAR) and its application to the study of spatial ordering in the EEG. Proc. San Diego Bio-Medical Symposium 15, 237-247.

Luders, E., Toga, A.W., Lepore, N., Gaser, C., 2009. The underlying anatomical correlates of long-term meditation: larger hippocampal and frontal volumes of gray matter. NeuroImage 45(3), 672-678.

Lutz, A., Greischar, L.L., Rawlings, N.B., Ricard, M., Davidson, R.J., 2004. Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. Proc. Natl. Acad. Sci. USA 101, 6369-16373.

Lutz, A., Slagter, H.A., Dunne, J.D., Davidson, R.J. 2008. Attention regulation and monitoring in meditation. Trends Cogn. Sci. 12(4), 163-169.

Lutz, A., Slagter, H.A., Rawlings, N.B., Francis, A.D., Greischar, L.L., Davidson, R.J., 2009. Mental training enhances attentional stability: neural and behavioral evidence. J. Neurosci. 29(42), 13418-13427.

Mesulam, M.M., 1990. Large-scale neurocognitive networks and distributed processing for attention, language, and memory. Ann. Neurol. 28, 597-613.

Mikulas, W.I., 1990. Mindfulness, self-control, and personal growth. In: Kwee, M.G.T. (Ed.), Psychotherapy, Meditation, and Health. East West Publications, London, pp. 151–164.

Milton, J., Jung, P. (Eds.), 2003. Epilepsy as a Dynamic Disease. Springer, Berlin.

Mizuhara, H., Wang, L.Q., Kobayashi, K., Yamaguchi, Y., 2005. Long-range EEG phase synchronization during an arithmetic task indexes a coherent cortical network simultaneously measured by fMRI. NeuroImage 27, 553-563.

Mulert, C., Jäger, L., Schmitt, R., Bussfeld, P., Pogarell, O., Möller, H.J., Juckel, G., Hegerl, U., 2004. Integration of fMRI and simultaneous EEG: towards a comprehensive understanding of localization and time-course of brain activity in target detection. NeuroImage 22, 83-94.

Murata, T., Takahashi, T., Hamada , T., Omori , M., Kosaka , H., Yoshida , H., Wada Y., 2004. Individual trait anxiety levels characterizing the properties of Zen meditation. Neuropsychobiol. 50, 189–194.

Nichols, T.E., Holmes, A.P., 2002. Nonparametric permutation tests for functional neuroimaging: A primer with examples. Hum. Brain Mapp. 15, 1-25.

Niedermeyer, E., Lopes da Silva, F., 2005. Electroencephalography: Basic Principles, Clinical Applications, and Related Fields, 5th ed. Lippincott Williams Wilkins, Philadelphia.

Nielsen, T., Abel, A., Lorrain, D., Montplaisir, J., 1990. Interhemispheric EEG coherence during sleep and wakefulness in left- and right-handed subjects. Brain Cogn. 14, 113-125.

Nolte, G., Bai, O., Wheaton, L., Mari, Z., Vorbach, S., Hallett, M., 2004. Identifying true brain interaction from EEG data using the imaginary part of coherency. Clin. Neurophysiol. 115, 2292-2307.

Northoff, G., Duncan, N.W., Hayes, D.J., 2010. The brain and its resting state activity -experimental and methodological implications. Prog. Neurobiol. 92(4), 593-600.

Nuwer, M.R., Comi, G., Emerson, R., Fuglsang-Frederiksen, A., Guérit, J.M., Hinrichs, H., Ikeda, A., Luccas, F.J., Rappelsburger, P., 1998. IFCN standards for digital recording of clinical EEG. International Federation of Clinical Neurophysiology. Electroenceph. Clin. Neurophysiol. 106, 259-261.

Okamoto, M., Dan, H., Sakamoto, K., Takeo, K., Shimizu, K., Kohno, S., Oda, I., Isobe, S., Suzuki, T., Kohyama, T., Dan, I., 2004. Three-dimensional probabilistic anatomical cranio-cerebral correlation via the international 10–20 system oriented for transcranial functional brain mapping. NeuroImage 21, 99-111.

Okuhata, S.T., Okazaki, S., Maekawa, H., 2009. EEG coherence pattern during simultaneous and successive processing tasks. Int. J. Psychophysiol. 72, 89-96.

Pascual-Marqui, R.D., 2002. Standardized low resolution brain electromagnetic tomography (sLORETA): technical details. Methods Find. Exp. Clin. Pharmacol. 24, Suppl. D, 5-12.

Pascual-Marqui, R.D., 2007. Instantaneous and lagged measurements of linear and nonlinear dependence between groups of multivariate time series: frequency decomposition. arXiv:0711.1455 [stat.ME], 2007-November-09. URL 21 Nov. 2011: <http://arxiv.org/abs/0711.1455>.

Pascual-Marqui, R.D., 2009. Theory of the EEG inverse problem. In: Quantitative EEG Analysis: Methods and Clinical Applications. Tong S. and Thakor N.V. (Eds.), Artech House, Boston, pp. 121-140.

Pascual-Marqui, R.D., Lehmann, D., Koukkou, M., Kochi, K., Anderer, P., Saletu, B., Tanaka, H., Hirata, K., John, E.R., Prichep, L., Biscay-Lirio, R., Kinoshita, T., 2011. Assessing interactions in the brain with exact low resolution electromagnetic tomography (eLORETA). Phil. Trans. R. Soc. A 369, 3768–3784.

Plummer, C., Wagner, M., Fuchs, M., Vogrin, S., Litewka, L., Farish, S., Bailey, C., Harvey, A.S., Cook, M.J., 2010. Clinical utility of distributed source modelling of interictal scalp EEG in focal epilepsy. Clin. Neurophysiol. 121, 1726-1739.

Ruchkin, D., 2005. EEG coherence. Int. J. Psychophysiol. 57, 83–85.

Singer, W., 2009. Distributed processing and temporal codes in neuronal networks. Cogn. Neurodyn. 3, 189–196.

Stam, C.J., 2000. Brain dynamics in theta and alpha frequency bands and working memory performance in humans. Neurosci. Lett. 286, 115-118.

Tei, S., Faber, P.L., Lehmann, D., Tsujiuchi, T., Kumano, H., Pascual-Marqui, R.D., Gianotti, L.R.R., Kochi, K., 2009. Meditators and non-meditators: EEG source imaging during resting. Brain Topography 22, 158-165.

Tononi, G., McIntosh, A.R., Russell, D.P., Edelman, G.M., 1998. Functional clustering: identifying strongly interactive brain regions in neuroimaging data. NeuroImage 7, 133–149.

Travis, F., 2001. Autonomic and EEG patterns distinguish transcending from other experiences during

Transcendental Meditation practice. Int. J. Psychophysiol. 42, 1-9.

Travis, F.T., Orme-Johnson, D.W., 1989. Field model of consciousness: EEG coherence changes as indicators of field effects. Int. J. Neurosci. 49, 203-211.

Travis, F., Wallace, R.K., 1999. Autonomic and EEG patterns during eyes-closed rest and Transcendental Meditation (TM) practice: The basis for a neural model of TM practice. Conscious. Cogn. 8, 302-318.

Travis, F., Shear, J., 2010. Focused attention, open monitoring and automatic self-transcending: Categories to organize meditations from Vedic, Buddhist and Chinese traditions. Conscious. Cogn. 19, 1110-1118.

Travis, F., Tecce, J., Arenander, A., Wallace, R.K., 2002. Patterns of EEG coherence, power, and contingent negative variation characterize the integration of transcendental and waking states. Biol. Psychol. 61, 293-319.

Travis, F., Haaga, D.A., Hagelin, J., Tanner, M., Arenander, A., Nidich, S., Gaylord-King, C., Grosswald, S., Rainforth, M., Schneider, R.H., 2010. A self-referential default brain state: patterns of coherence, power, and eLORETA sources during eyes-closed rest and Transcendental Meditation practice. Cogn. Process. 11, 21-30.

van den Hurk, P.A., Janssen, B.H., Giommi, F., Barendregt, H.P., Gielen, S.C., 2010. Mindfulness meditation associated with alterations in bottom-up processing: psychophysiological evidence for reduced reactivity. Int. J. Psychophysiol. 78(2), 151-157.

Vitacco, D., Brandeis, D., Pascual-Marqui, R., Martin, E., 2002. Correspondence of event-related potential tomography and functional magnetic resonance imaging during language processing. Hum. Brain Mapp, 17, 4-12.

Wackermann, J., 1996. Beyond mapping: estimating complexity of multichannel EEG recordings. Acta Neurobiol. Exp. (Wars) 56, 197-208.

Wackermann, J., 1999. Towards a quantitative characterisation of functional states of the brain: from the non-linear methodology to the global linear description. Int. J. Psychophysiol. 34, 65-80.

Walsh, R., 1982. The original goals of meditation. Am. J. Psychiatry 139:1525–1526.

Walter, D.O., Rhodes, J.M., Adey, W.R., 1967. Discriminating among states of consciousness by EEG measurements. A study of four subjects. Electroenceph. Clin. Neurophysiol. 22, 22-29.

Weiss, S., Mueller, H.M., Schack, B., King, J.W., Kutas, M., Rappelsberger, P.. 2005. Increased neuronal communication accompanying sentence comprehension. Int. J. Psychophysiol. 57, 129-141.

White, D., Ciorciari, J., Carbis, C., Liley, D., 2009. EEG correlates of virtual reality hypnosis. Int. J. Clin. Exp. Hypn. 57, 94-116.

Worrell, G.A., Lagerlund, T.D., Sharbrough, F.W., Brinkmann, B.H., Busacker, N.E., Cicora, K.M., O'Brien, T.J., 2000. Localization of the epileptic focus by low-resolution electromagnetic tomography in patients with a lesion demonstrated by MRI. Brain Topography 12, 273-282.

Yang, L., Wilke, C., Brinkmann, B., Worrell, G.A., He, B., 2011. Dynamic imaging of ictal oscillations using non-invasive high-resolution EEG. NeuroImage 56(4), 1908-1917.

Zumsteg, D., Lozano, A.M., Wieser, H.G., Wennberg, R.A., 2006. Cortical activation with deep brain stimulation of the anterior thalamus for epilepsy. Clin. Neurophysiol. 117, 192–207.

Zumsteg, D., Wennberg, R.A., Treyer, V., Buck, A., Wieser, H.G., 2005. H2(15)O or 13NH3 PET and electromagnetic tomography (LORETA) during partial status epilepticus. Neurology 65, 1657-1660.

3. General discussion

The aim of the present thesis was to study idiosyncrasies and commonalities of different meditation practices from different meditation traditions. In study I the focus was on the differences between two Qigong meditation practices ('Thinking of nothing' and 'Qigong') and their differences to no-task resting. In study II the focus was on the differences between the Zen meditation practice Zazen and no-task resting. Study III focused on five meditation traditions: Qigong, Sahaja Yoga, Ananda Marga Yoga, Tibetan Buddhism and Zen. For each tradition one meditation practice leading to a deep meditative state was compared to a no-task resting condition. The commonalities across traditions were reported. All three studies revealed some practice related idiosyncrasies. Study III in addition revealed very striking commonalities between the 5 groups of meditators while performing their respective meditation practices. The results of these studies are reported in sections 2.1. - 2.3, followed by their respective discussion. In the following sections, these three studies are related to each other and discussed more generally under the topic of the present thesis, namely idiosyncrasies and commonalities of different meditation practices. Limitations of these studies are discussed and an outlook is given for future research. Also, section 3.3. briefly revisits the topic of meditation taxonomies.

3.1. Idiosyncrasies

Meditation practices often start out as focused attention and in later stages allow open monitoring. Some practices, like Zazen already start with open monitoring. The chosen object for the focus of attention differs widely between practices and it is reasonable to assume that focusing on one's breathing or other bodily sensations requires different brain electric activations than focusing on a thought or an external object like the flame of a candle or the sound of drumming. The presented studies are concerned with two different Qigong meditation practices and the Buddhist Zazen practice. The reported electrophysiological characteristics of the three practices differ widely. Study III was primarily aimed at finding commonalities between different practices, but the reported results also bring to light functional connectivity differences between the five practices.

In study I we learn that 'Thinking of Nothing' clearly differs from 'Qigong' in the underlying brain electric activations. 'Thinking of Nothing' revealed stronger activity in anterior left prefrontal areas while 'Qigong' showed stronger posterior right parietal activity when directly compared. Compared to no-task resting, "Thinking of Nothing" showed acivations in anterior areas, ‘Qigong’ in posterior areas, albeit at uncorrected $p<0.05$. As pointed out in study I, it is unclear into which category of the existing meditation classifications the two practices fit. The breath-synchronized arm movements during ‘Qigong’ have an aspect of FA meditation as the focus of attention, at least initially, needs to be on the breath and arm movements. The brain-electric findings (i.e. the lack of activation of frontal motor areas) though suggest that the breath-synchronized arm movements might have a strong component of automaticity due to years of experience and thus do not require much attentional effort. The expressed goal of transcending of this practice is in line with this interpretation. On the other hand, the involvement of BAs 7, 40, 5 and 31 are in line with increased spatial attention probably needed for monitoring the slow arm movements. The practice of ‘Thinking of Nothing’, often performed prior to ‘Qigong’, has the main focus on reducing spontaneous mentations, thus entering a state of emptiness without thoughts, which is then continued in ‘Qigong’ until transcendence is reached. Unfortunately, with the lack of more extensive descriptions of subjective experiences during this practice, it remains unclear whether ‘Thinking of Nothing’ has an aspect of open monitoring, characterized by detached observation of ongoing experiences, thus reducing the amount of stimulus-related mentations and ultimately leading to a quiet, empty mind. The results are not readily integrated in the brain networks expected to play a role during meditation (see section 1.3.3.). This could have several reasons. First, it is possible that both meditation practices share some common networks, which cancel out when subtracting one from the other. The comparison of both practices to resting though seems to imply that there are no common networks involved. Then again, resting itself could be changed by long-term practice of meditation, itself showing aspects of meditation (e.g. detached monitoring of ongoing experience), thus clouding such networks in comparisons (see also section 3.4.). A more probable reason is the fact that study I compares brain electric measurements averaged over a whole meditation session. The practice of meditation, at least before reaching the deepest states, is a dynamic process, one of monitoring, alerting, refocusing and sustaining attention, engaging different networks over time (see Hasenkamp, Wilson-Mendenhall et al. 2012, Malinowski 2013). Averaging over time makes the detection of such nuances impossible. Yet another reason could be the mentioned difficulty of fitting these practices in some classification scheme or other, thus rendering the expected involvement of certain brain networks (mostly based on reflections about FA practices) questionable.

In sum, study I reveals differences between the two Qigong practices of ‘Thinking of Nothing’ and ‘Qigong’ in brain electric activity patterns. It also exemplifies the need to closely study the different practices rather than fitting them in some classification scheme, thus missing the idiosyncrasies of each practice. And it highlights the need for gathering detailed descriptions of subjective experiences in future studies.

In study II we learn in what way Zazen differs from no-task resting in its brain electric activity patterns. The widely used classification into FA and OM meditations (Dunn, Hartigan et al. 1999, Lutz, Slagter et al. 2008, Raffone and Srinivasan 2010) is based on Buddhist traditions and Zazen is the classical example of an OM practice. Do our results in this case fit the brain networks expected to be involved during OM? Indeed, several hubs of the DMN showed reduced activity during Zazen: PCC, precuneus, angular gyrus, parietal areas and parahippocampus. While DMN activity was reduced, activity in parts of the anti-correlated attention-related task-positive network (prefrontal areas, insula, somatosensory and motor areas) was increased. Zazen at least partly activates and deactivates networks as expected. As with the Qigong meditation from study I, a finer grained analysis looking for the involvement of other networks (i.e. salience, executive) is difficult due to the averaging over a complete meditation session of 60 minutes. Also, in this study there was no information about subjective experiences or meditation depth over the duration of the session. In fact, during discussions with the meditators in the preparatory phase of the study, it became clear that they did not wish to be given a questionnaire about experiences and depth of meditation after the meditation session. They claimed that the anticipation of such a questionnaire would install a hindering meta-awareness during meditation in order to be able to track the ongoing experience. This indeed is contrary to the idea of Zazen not to get attached to the ongoing experience. This means that we do not know what exactly happened during the meditation session. It is quite possible and even probable that within subjects and across subjects we averaged data on stages of meditation differing in depth and cognitive characteristics. How to solve the problem of post-hoc descriptions of subjective experiences and depth of meditation, needs to be figured out in future studies. In a time of increasing ethical demands, it might be a problem not to inform the subjects beforehand about the questionnaires they will be given. And then again, even if given, it is unclear whether detached non-clinging observation of experiences during a one-hour session of meditation can be reliably reproduced by the meditators after the meditation.

In sum, study II reveals brain electric idiosyncrasies of Zazen, a typical open monitoring meditation. The results give some validity to the models proposing the involvement of the anticorrelated task-positive and task-negative networks during meditation. Study II joins study I first in showing the need for more data on subjective experiences during meditation and second in begging for a temporally finer grained approach when studying the idiosyncrasies of different meditation practices.

Although study III specifically focused on commonalities between deep states of meditation reached through practices from 5 different traditions, the results also tell us a few things about the respective idiosyncrasies of these practices. It is clear that the significantly reduced functional connectivities differ in number and location between the 5 traditions. For example, Qigong and Sahaja Yoga showed much more significant connectivity reductions in the delta band than the other three groups. When looking at the conventionally computed head surface coherences, Zazen had by far the highest number of reduced coherences in the alpha, beta and gamma frequency bands.

Thus, even study III reveals differences between practices. In the next section, when discussing the commonalities found, I will point out the problem of having no meditation depth measures in study III. There is the possibility of the different groups/subjects not having reached the optimal deep state of meditation. In such a case, we possibly found the differences between the practices. It is conceivable that these differences would have disappeared completely if all subjects had reached a common deep state of non-duality. Whatever the reason, the results clearly show differences between practices (or states) and thus again highlight the need to further study the idiosyncrasies of the different practices and to gather subjective depth and quality ratings and reports about subjective experiences during meditation.

3.2. Commonalities

Due to the similar subjective descriptions of deep meditation states, it is not only conceivable but also supported by the results of study III that there are brain electric commonalities underlying states of deep meditation in experienced meditators from different traditions using different practices. Meditation training is a long process of de-automatization, of relearning to effortlessly maintain a wide and open awareness and to experience percepts non-judgmentally in the present moment. Beginning practitioners often use practices with a narrow focus of attention on a chosen object to calm their mind. Through prolonged practice they become increasingly competent in effortlessly keeping their focus on the object and then start cultivating an open awareness (Lippelt, Hommel et al. 2014). Experienced meditators shift to more open monitoring practices and reach deeper states characterized as oneness, where the duality of observer and object is dissolved. These deeper states are more likely to show electrophysiological commonalities because the meditational exercise itself becomes less central and eventually disappears.

On a side note, experience in meditation expressed in years or hours does not really tell us much about the actual proficiency of the practitioner. Rather, it seems an indicator for the practioner's commitment or endurance skills. It is in the nature of meditation practices that there is no systematic or linear advancement in the proficiency of the practitioner (Lutz, Slagter et al. 2008). Meditation can be viewed as a method of personal development, in a therapeutic sense, of de-automatization of learned responses to internal and external experiences, of learning to accept what is, with a detached, non-judgmental stance (see also Mikulas 1990). As such, each practitioner will have to pave his own way, overcome his own personal obstacles on his way to deeper meditation states described as being one with everything or as emptiness. Such deepest meditation states can be encountered around the next corner or it can take a lifetime of practice and they can still wait around yet another corner. Hours or years of practice thus do not necessarily equal proficiency in meditation, although they might indicate proficiency in the use of a certain meditation practice.

The subjective experience of the practitioner seems paramount as an indicator for the depth of the achieved meditation states. In study III the practitioners were asked to do that meditation practice which they considered to lead to the deepest optimal meditation state. Unfortunately, there was no actual depth rating included in the study design, which is a clear limitation of the study. Possibly the obvious differences of functional connectivity in number and location between groups could have been disentangled by the missing information of the actual depth of the performed meditation. Of course, subjective depth ratings present a problem. There are some questionnaires (e.g. Ott 2001, Piron 2001) that offer items consisting of typical experiences described by meditators. In the Piron study, the questionnaire items could be clustered in 5 stages of increasing meditation depth: hindrances, relaxation, personal self, transpersonal qualities and transpersonal self (non-duality). An additional approach was proposed by Ott (2001): practitioners are asked to draw a line in a rectangular box, whith the x-axis representing the time spent in meditation and the y-axis respresenting the depth of the meditation state related to the personal deepest meditation state experienced in the past (the deepest state being at the bottom of the box). While this is an interesting approach, the deepest state experienced in the past by one practitioner might still be miles away from the deepest state of another practitioner. On the other hand, subjective depth criteria across 40 experienced meditation teachers of different traditions showed highly correlated depth ratings and a coefficient of concordance of 0.7 (Piron 2001). In addition to depth ratings, reports about the subjective experiences during the recorded meditation session should be included in future studies. While in study III we have short descriptions of the deep meditation states targeted by the respective practice of each group, we do not know whether the targeted deep states were actually reached and what their subjective nuances might have been.

Despite all the uncertainty regarding the actually achieved depth and characteristics of the meditation state, study III reports the common phenomenon of decreased functional connectivity in all 5 meditation traditions and the respective practices used. This is a remarkable commonality and quite an unexpected finding. Based on the extensive TM literature (e.g. Levine 1976, Dillbeck and Bronson 1981, Gaylord, Orme-Johnson et al. 1989, Travis and Orme-Johnson 1989, Travis and Wallace 1999, Travis 2001, Travis, Tecce et al. 2002, Travis and Shear 2010) reporting mostly alpha coherence increases during TM and the hypothesis of some commonality of deep meditation states across traditions, one would have expected increased connectivity during meditation. This was not the case, not even in scalp based conventional coherence computations (also used in the TM literature), except for the group of Qigong practitioners, who did show some alpha-1 increases in scalp coherence. But when looking at the intracerebral lagged connectivities, there were also only decreases in the Qigong group. It is not necessarily surprising that our intracerebral lagged connectivity results differed from the reported scalp based coherence results of the TM literature. The two methods can be expected to contribute to differing results: while an increase in source strength increases conventional head-surface coherence due to volume conduction (Pascual-Marqui 1993), intracortical lagged coherence is exempt from this problem and thus yields differing results purely influenced by physiological connections (Pascual-Marqui 2007, Pascual-Marqui, Lehmann et al. 2011). But our scalp based coherence computations also mostly yielded reduced values during meditation. It is therefore possible that the practice of TM differs from the 5 practices we studied. TM seems to fit in the separate category of automatic self-transcending, just like Acem meditation, which was also not included in our study. In a current project a group of experienced TM practitioners is being studied and their EEG data analyzed using the methods of study III. Unfortunately, there are no results yet and the question whether TM differs from our five groups in regard to functional connectivity is still unanswered.

Our main finding of reduced functional connectivity during meditation finds support in a recent MEG-study (Marzetti, Di Lanzo et al. 2014). Theravada Buddhist monks performed FA and OM meditations and a no-task resting condition. When compared to rest, both FA and OM showed reduced functional connectivity in the alpha frequency band studied. The study specifically targeted the PCC as a core DMN hub and its connectivity to the rest of the brain. During FA, the PCC was less coupled to the left superior frontal gyrus, the left superior middle frontal gyrus, the left lateral temporal cortex and the bilateral ACC than during rest. During OM, the PCC was less coupled to the left intraparietal sulcus. Likewise, it would be of great interest to know how our findings of reduced functional connectivity relate to brain networks of interest in meditation (e.g. the DMN). Unfortunately the 19 regions of interest (ROIs) used in study III cannot readily be attributed to any resting state or other network. When planning study III, the idea was to assess globally, as unbiased as possible, the functional connectivity in the brain during meditation and resting. Therefore, 19 evenly distributed (10-20 system) electrode positions were used as seeds for the ROIs, which thus evenly covered the underlying attributed cortex voxels. This is a bottom-up approach, without theoretical restriction to certain brain areas or networks. To disentangle the various connectivity changes found in the different groups, it would be interesting to reanalyze the data with regard to possibly relevant networks using ROIs based on these networks. The way it was done though, there is no justification to speculate on the possible interpretation of the results in terms of distributed networks.

How can the general reduction of connectivity found in all 5 groups explain the common subjective descriptions of being one with everything and losing the ego-boundaries? In order to uphold a feeling of self, one has to constantly demarcate oneself from internal and external realities. This means that many processes need to be integrated and many brain areas need to work in concert for this to happen. During meditation, connectivity between brain areas generally decreases, meaning that cooperativity between different brain areas decreases and the many processes involved in demarcating oneself from the world are weakened and less integrated. When the boundaries between oneself and the inner and outer world get weaker or even disappear during deep states of meditation, one becomes the world, which would explain the feeling of being one with everything. There is no subject-object duality left. The differences in number and location of reduced connectivities in the five groups could mean that not all subjects or groups reached the same deep state of non-duality or that some did not reach such a state at all. In case of the latter, we might have measured connectivity changes related to the practice rather than the state achieved. Since every group used a different practice, it is probable that the different practices take different routes in shutting down cooperation between brain areas. The differences between practices need to be studied in more depth in future studies. Despite the differences, the clear message here is that all studied practices are shutting down cooperation between certain brain areas, thus loosening the constraints on the self and thus ultimately leading to the common subjective experience of being one with everything.

Another interesting result of study III is that going in and coming out of meditation is different and this result holds for all five groups. This implies that the reduction of connectivity when going into meditation has different underlying processes than the increase of connectivity when going out of meditation. This is nicely illustrated by the topographic differences of the principal functional connectivity in the delta band. Here we observe almost orthogonal principal functional connectivities for entering and exiting meditation, wheras the beta-2 band basically shows a 'simple' reversal. The computation of the principal functional connectivity is based on the significant connectivity differences found between meditation and rest in each group. While still respecting the brain space, it is a rather strong abstraction and difficult if not impossible to relate to actual brain areas or brain networks. To my knowledge, the found difference between entering end exiting meditation is not exactly a surprising but a novel finding nonetheless. It seems worthwhile for future studies to investigate in more detail how the brain electric mechanisms involved in entering and exiting meditation differ. Using ROIs based on possibly relevant networks could shed more light on this issue. In view of the apparent differences in number and location of found connectivity differences between groups, it seems imperative to study each group separately in this way.

3.3. Meditation taxonomies: some thoughts

The different taxonomies for meditation practices that have been proposed in the past (Fischer 1971, Kiely and Gellhorn 1972, Davidson and Goleman 1977, Mikulas 1990, Dunn, Hartigan et al. 1999, Lutz, Slagter et al. 2008, Raffone and Srinivasan 2010, Travis and Shear 2010) have already been mentioned in section 1.3.2. One major classification is the distinction between FA and OM, which is a distinction on the attention dimension. It is interesting to note that more recently a return to earlier conceptions was propagated. Indeed, Amihai and Kozhevnikov (2014) claim that distinctions between arousal and relaxation might be more useful for the categorization of meditation practices than distinctions based on the attention dimension, as the latter have proven to be insufficient in clearly differentiating between practices. The problem with the attention dimension is that many practices belong to both categories – FA and OM (Cahn and Polich 2006). Often a practice starts out as focused attention to calm the mind and reduce intruding thoughts and then allows the focus to become more open and even completely stray away from the original object of attention. Also, as Mikulas (1990) noted, concentration and mindfulness are highly intertwined; while emphasizing one, there will always be some aspect of the other. Apart from not clearly differentiating between the different practices, some practices do not fit in the attention dimension at all. Both FA and OM imply some form of subject-observing-object (Josipovic 2010). States of non-duality are outside of the attention dimension. States of transcendence therefore do not fit into the FA-OM classification and Travis

& Shear (2010) rightfully introduced a third category of automatic self-transcending. Josipovic (2010, 2014) points out the importance of distinguishing between practices that stay within the dualistic subject-object cognitive structure and practices that transcend this structure laying bare the nondual awareness underneath. In view of the complexity of the subject matter of taxonomies, he proposes a multidimensional approach: of import are the targeted states of consciousness, the duality-nonduality continuum, the stages of expertise, the attentional strategies and the working memory load, as well as the objects of meditation (Josipovic 2010). Awasthi (2012) even demands to take into account the philosophical positions that underlie the phenomenology of meditation states from the different meditation traditions. Thomas and Cohen (2014) propose to include into the methodological paradigm the place (the cultural setting), the person (life situation of the practitioner), the practice (details/instructions) and the phenomenology (state of consciousness). Nash and Newberg (2013) note that past taxonomies are based on first-person perspectives. They propose for future taxonomies to rely on third-person paradigms as successfully used in affective and cognitive science, combined with some necessary first-person perspectives.

A common stumbling block when studying meditation is the difficult distinction between the meditation practice and the meditation state possibly reached through that practice (see also Nash and Newberg 2013). Brain-electric mechanisms underlying the processes involved in transcending the subject-object duality might very well be different from the brain-electric mechanisms involved when such a state of nondual awareness is finally reached. The studies presented in this thesis are not exempt from this problem. Especially study III relies in no small part on the meditators to reach a deep state of meditation as the commonalities of such deep states reached via different practices were the explicit target of the investigation.

Nash and Newberg (2013) propose to distinguish six stages during meditation and three classes or domains of practices. The six stages are: normal waking state, intention to begin, preliminaries (preparing the setting for meditation), method, enhanced mental state and intention to finish. The three domains are: the affective domain (practices involving enhanced affective states, e.g. compassion meditation), the null domain (practices creating an empty state devoid of phenomenological content, e.g. TM), and the cognitive domain (all other practices, e.g. insight or mindfulness states). This seems a promising approach for future studies.

3.4. Potential problems and limitations

Several problems and limitations of the presented studies were addressed in the respective studies. They concern the resting state as well as the meditation state and the subjective reports of the meditation practitioners.

What is the problem with the the control state of no-task resting? A comment often made by experienced meditators is that they feel unable to not meditate. Their resting state is changed after years of practice and this is not only a subjective feeling. Indeed several studies report that long-term meditation alters the resting state EEG (Tebēcis 1975, Lutz, Greischar et al. 2004, Aftanas and Golosheykin 2005, Tei, Faber et al. 2009). Brewer et al. (2011) suggested an altered default mode during resting in meditators. DMN changes in functional connectivity during resting were reported for long-term practitioners of mindfulness meditation when compared to novices (Taylor, Daneault et al. 2012). If their own resting state is already changed, one might consider comparing against the resting state of non-meditators. But selecting a matched non-meditator control group is difficult, especially for long-term meditators (see also Davidson 2010, Tang and Posner 2013), as it is not known how the meditators differed before taking up their practice. In all three studies presented in this thesis, differences reported between meditation and resting might be influenced by a changed resting state which possibly obfuscated additional differences.

And what is the problem with the meditation state itself? As mentioned previously, distinguishing between practice and targeted state of meditation is difficult. The practice itself might vary over a meditation session, the different aspects of a practice (e.g. focused attention to lessen intruding thoughts and increasing mindfulness or open monitoring once the mind has settled) having different weights over time. This means intrapersonally varying experiences during the practice of meditation. Indeed, the multitude of results found in the meditation literature and also the results of the presented studies (chapter 2) seem to suggest such a heterogeneity in the meditation practices studied. The practice of meditation is a dynamic process and it is reasonable to assume that a typical meditation session moves or cycles through different stages (see also Nash and Newberg 2013). Averaging data over different stages of meditation might have led to the diverging results reported (see also Tang and Posner 2013). The problem is one of depth and of cognitive processes involved in each stage of a meditation session. Already in 1972 different EEG patterns were reported and related to different subjective experiences during the same meditation session (Henrotte, Etevenon et al. 1972). Intermittent high amplitude gamma activity was already described by these authors and much later also reported by Lutz and colleagues (Lutz, Greischar et al. 2004). Also theta bursts preceded and followed by increased alpha activity have been reported during TM (Hebert and Lehmann 1977). These theta bursts were hypothesized to be a “manifestation of a state adjustment mechanism” (Hebert and Lehmann 1977, p. 404). Changes in theta and alpha activity throughout a meditation session indicating different stages of meditation have also been reported by Tsai et al. (2013). Meditation depth ratings (Ott 2001) also show changes in depth over a meditation session. It appears fruitful to investigate in more detail the dynamics of cognitive processing at a much finer time resolution during the practice of meditation. Efforts have been made to look at different phases of a meditation session. A model was proposed that describes four intervals in a cognitive cycle during breath-focused meditation: mind wandering, awareness of mind wandering, shifting of attention, and sustained attention (Hasenkamp, Wilson-Mendenhall et al. 2012). Another study differentiated periods of transcending from periods of undirected mentations during a TM session (Travis 2001). Based on EEG and peripheral measurement variables, the possibility of building an automatized staging tool for disciminating different states during the practice of meditation has been investigated (Hinterberger, Kamei et al. 2011). It has been argued that novices need more FA-style practices in order to train attentional stability, clarity, and awareness of the current mental state, thus enabling OM-style practices with their moment-to-moment detached observation of all experiences (Malinowski 2013). Tang, Rothbart and Posner (2012) describe three stages of meditation, an early, an intermediate and an advanced stage, with increasingly less conscious effort involved. The early stage needs conscious control and mental effort to eliminate attention to external stimuli. If voluntary control is used, then the attention control networks (including lateral PFC and parietal cortex) are involved. Especially novices need more effort. If less effort is used, the ACC is mainly involved. In the intermediate stage, effort is only needed to deal with distractions and mind wandering. This requires awareness of mind wandering, shifting of attention back to practice and sustaining attention, thus also involving parts of the attention networks (including lateral PFC and parietal cortex). The advanced stage needs no or little effort and seems to involve the ACC, the left insula and the striatum, whereas activity in the lateral PFC and parietal areas is reduced. These descriptions are based on Integrative Body-Mind training (IBMT), a mindfulness meditation (Tang, Rothbart et al. 2012). In sum, it seems clear that the practice of meditation is a dynamic process involving different stages of meditation, probably more so for novices than advanced practitioners. And the goal of future studies should be the disentanglement of different meditation stages.

A limitation of the studies presented in this thesis is the lack of subjective reports. Systematic reports about subjective experiences during meditation are rare, which could have several reasons, as already outlined in study I. A main reason could be that experiences, especially experiences of deep meditation states involving non-duality, might be difficult to verbalize. Talking to the meditators that participated in our studies, I often noticed that they use tradition-specific terminology in describing their experiences during meditation. This could mean that this habitual terminology offers descriptions for experiences that might otherwise be difficult to verbalize or it could mean that actual experiences are disregarded in favour of what the meditators know is to be expected to happen during meditation. Actual experiences might thus be shaped restrospectively by tradition-specific vocabulary. Another reason for the lack of systematic reports on subjective experiences might be the fact that such reports have to be gathered after the meditation session. As mentioned before, in study II the Zen practitioners after they were given a detailed description of the study design, refused to give reports after each meditation session, because they claimed that they would need a constant meta-awareness tracking their experiences during meditation to be able to later report on them. They considered this in strong opposition to and very disturbing for the practice of Zazen. For all these reasons, gathering reports on subjective experiences during meditation is not trivial. Nonetheless, efforts should be made in future studies to take into account as much as possible such reports, including depth and quality ratings as well as subjective descriptions of what really happened during the meditation session under scrutiny. Such reports would help considerably in unraveling the underlying brain-electric mechanisms. See also Walach (2014) for a review of the historical background and a discussion on first-person and third-person view of inner experience and the requirements for an epistemology of inner experience.

A further limitation concerns study III, which used evenly distributed ROIs in a bottom-up approach for connectivity analysis. Functional interpretation of the results for example in the context of distributed networks was therefore not possible (see also section 3.2.). While this bottom-up approach allowed a first general look at what happens to functional connectivity during meditation, future studies need to include theory-driven selection of regions of interest in order to refine this general finding and relate it to specific networks.

3.5. Outlook

Considering the problem of averaging data over different meditation stages within one session, it becomes apparent that one goal of future studies must be to have a more fine-grained look at what goes on during a typical meditation session. This might be different from practice to practice and therefore studying the idiosyncrasies of each practice remains an important task for the future as well. How can we sharpen our lens for looking at what is happening during a meditation session?

Methodologically, the EEG microstate analysis (cf. 1.4.3.) is a prime candidate for studying in more depth the different parts or stages of a meditation session. A current project evaluates microstate parameters in TM practitioners during periods of transcendence (attending to a mantra) and during periods of undirected mentations within a meditation session of 20 minutes. In an earlier study (Travis 2001), the practitioners were interrupted in their practice by the ring of a bell and asked whether they had been transcending or had been having ‘other’ experiences. In the current project, the practitioners were asked to press a button whenever they noticed that they had been involved in undirected mentations, upon which they then had to re-attend to their mantra. The preliminary results of the microstate analysis perfomed on these data look promising: the prominence of microstate classes A and C decreased and the prominence of class D increased significantly during transcending (Faber, Lehmann et al. 2014). It would be really interesting to use the microstate analysis strategy and the paradigm of the current TM study on other meditation practices. As mentioned in section 1.1.1. an important difference of TM to other meditation practices is the acceptance of undirected mentation as part of the meditation process. Other practices consider ‘mind wandering’ as off-task and actively try to suppress intruding thoughts. The involved processes should influence the microstate parameters.

Meditation practitioners are excellent subjects for learning more about the functional significance of the different microstate classes. It has been shown that experienced meditation practitioners have better introspective accuracy than novice practitioners (Fox, Zakarauskas et al. 2012). Therefore asking long-term practitioners about their subjective experiences during meditation seems promising. In a first step, one could extract the microstate classes that best fit the EEG recorded during a meditation session. Then, in a second step one could monitor online during meditation the parameters of the extracted microstate classes. At points where a certain class is dominant, one should then ask the subjects about their subjective experience. Collecting such class-based reports, one could establish the functional meaning of each class. In a final step one could segment meditation sessions based on the prevalence of each class. Such an analysis approach could possibly help to distinguish meditation practices based on several criteria: e.g. degree of segmentation (indicator for the stableness of a meditation state), prominence of different microstate classes and thus different functional processes, and distribution of the prominent classes over time (e.g. change from FA aspects to OM aspects). Another new and promising method is an eLORETA-based (Pascual-Marqui 2007) functional ICA approach that extracts cross-frequency independent brain networks (Pascual-Marqui and Biscay-Lirio 2011). This method has been successfully used to extract twelve cross-frequency spatially distributed electrophysiological networks during eyes closed resting (Aoki, Ishii et al. 2015) and we currently use it in a study uncovering the cross-frequency independent networks underlying different modalities of thinking (Milz, Pascual-Marqui et al. in preparation). This method might yield new insights in future meditation studies as well.

The main finding of study III is the generally decreased functional connectivity in deep meditation states across the five traditions studied. As briefly mentioned before, in an ongoing study, a group of practitioners from the tradition of Transcendental Meditation is being investigated with the same methodology. It is unclear whether this group will also show this reduced connectivity as the practice of TM has been claimed to belong to a separate class of practices not fitting in other taxonomies like FA and OM practices. In order to find more commonalities between different practices, these practices and the states of consciousness involved in these practices need to be better described on several dimensions (see also section 3.3.). Clearer demarcations of possibly different deep states of meditation need to be made. Therefore subjective descriptions that go beyond tradition-bound terminology are needed. This will possibly require the development of new methods for gathering first-person reports or new methods for evaluating meditation depth (see also Walach 2014). Once groups of similar states or practices can reliably be made, further commonalities might surface.

The reported finding that different brain electric mechanisms lead into meditation than out of meditation should be a future topic in meditation research. In order to disentangle these mechanisms, one can now focus on specific brain networks (attention, salience, orienting, executive and default mode) most probably involved in these state changes.

In view of the reported benefits of the practice of meditation and the demand for better descriptions of practices on several dimensions including more information on the practitioner himself, it seems adequate to include personality characteristics in future studies. Some practices might benefit certain persons more or some persons might have easier access to certain practices possibly depending on the brain electric mechanisms and cognitive functions involved. The possibility of more personalized meditation practices (reducing dropout rates and increasing benefits) should be investigated in future studies.

3.6. Conclusion

My questions as well as my expectations when I started my work on this thesis project were simple enough. So many different meditation traditions, so many different meditation practices. And so similar descriptions of deep meditation states across traditions. There must be many brain electric differences involved in these very different practices. And there also must be brain electric commonalities considering the similar subjective descriptions at least of deeper meditation states.

The data and results from the three studies presented in this thesis support my expectations. There are many differences between meditation practices in brain electric activity. ‘Qigong’ is different from ‘Thinking of nothing’ and connectivity changes from resting to meditation differ in number and location between practices from 5 different meditation traditions. Also, all investigated practices showed idiosyncratic differences to no-task resting. Given the idea that most meditation practices have a common goal, it is therefore of great interest to describe what different brain electric mechanisms can lead to this same goal. Describing in greater detail the brain electric idiosyncrasies of each meditation practice (or category of meditation practices when considering different classification systems) is needed to help differentiate these processes and thus possibly enable in the future more informed individualized meditation practices taking into account emotional, attentional and personality characteristics of the interested individuals. The presented data on the two qigong practices ‘Thinking of Nothing’ and ‘Qigong’ and the Zazen meditation practice from the Zen tradition add a few such detailed descriptions to the growing pool of already existing descriptions of other practices. Hopefully in the future many more will follow.

While still showing clear brain electric differences, deep meditation states generated by practices from different traditions could be shown in study III to have a very striking brain electric commonality: a general reduction of functional connectivity. The different practices can be viewed as different roads to the same goal. Possibly all roads lead to Rome. Of course, Rome wasn’t built in a day. And likewise, reaching deep states of meditation described in similar words across traditions also needs dedication, perseverance and regular practice over many years. It will be interesting to see if future studies can isolate other commonalities of deep meditation states. And it will be important to gather detailed subjective descriptions of these states to get a more informed knowledge about the subjective similarities of these deep meditation states or the differences that possibly still differentiate them from one another.

Considering the limitations of the presented studies (i.e. lack of subjective reports, lack of distinction between meditation practice and meditation states), further studies are required to gain a more fine-grained look at different meditation stages and the associated subjective experiences. Such studies might require other methodological approaches, such as for example EEG microstate analysis.

Overall, the work on these studies concerned with idiosyncrasies and commonalities of different meditation practices yielded a few answers but mostly many more questions. This is in line with Prof. Dietrich Lehmann's last words before he passed away on June 16th, 2014: 'There is still so much to do in science!'

4. References

Aftanas, L. and S. Golosheykin (2005). "Impact of regular meditation practice on EEG activity at rest and during evoked negative emotions." International Journal of Neuroscience **115**(6): 893-909.

Amihai, I. and M. Kozhevnikov (2014). "Arousal vs. Relaxation: A Comparison of the Neurophysiological and Cognitive Correlates of Vajrayana and Theravada Meditative Practices." PloS One **9**(7): e102990.

Anand, B., G. Chhina and B. Singh (1961). "Some aspects of electroencephalographic studies in yogis." Electroencephalography and Clinical Neurophysiology **13**(3): 452-456.

Andreou, C., P. L. Faber, G. Leicht, D. Schoettle, N. Polomac, I. L. Hanganu-Opatz, D. Lehmann and C. Mulert (2014). "Resting-state connectivity in the prodromal phase of schizophrenia: insights from EEG microstates." Schizophrenia Research **152**(2): 513-520.

Aoki, Y., R. Ishii, R. D. Pascual-Marqui, L. Canuet, S. Ikeda, M. Hata, K. Imajo, H. Matsuzaki, T. Musha, T. Asada, M. Iwase and M. Takeda (2015). "Detection of EEG-Resting State Networks by LORETA-ICA method." Frontiers in Human Neuroscience **9**.

Austin, J. H. (2013). "Zen and the Brain: Mutually Illuminating Topics." Frontiers in Psychology **4**.

Awasthi, B. (2012). "Issues and perspectives in meditation research: in search for a definition." Frontiers in Psychology **3**.

Bærentsen, K. B., H. Stødkilde-Jørgensen, B. Sommerlund, T. Hartmann, J. Damsgaard-Madsen, M. Fosnæs and A. C. Green (2010). "An investigation of brain processes supporting meditation." Cognitive Processing **11**(1): 57-84.

Becker, D. E. and D. Shapiro (1981). "Physiological responses to clicks during Zen, Yoga, and TM meditation." Psychophysiology **18**(6): 694-699.

Benson, H., M. Malhotra, R. F. Goldman, G. D. Jacobs and P. J. Hopkins (1990). "Three case reports of the metabolic and electroencephalographic changes during advanced Buddhist meditation techniques." Behavioral Medicine **16**(2): 90-95.

Berger, H. (1929). "Über das Elektroenzephalogramm des Menschen I–XIV." Arch. Psychiat. Nervenkr. **87**: 527-570.

Berkovich-Ohana, A., J. Glicksohn and A. Goldstein (2012). "Mindfulness-induced changes in gamma band activity–implications for the default mode network, self-reference and attention." Clinical Neurophysiology **123**(4): 700-710.

Berkovich-Ohana, A., J. Glicksohn and A. Goldstein (2013). "Studying the default mode and its mindfulness-induced changes using EEG functional connectivity." Social Cognitive and Affective Neuroscience.

Berman, A. E. and L. Stevens (2015). "EEG manifestations of nondual experiences in meditators." Consciousness and Cognition **31**: 1-11.

Betting, L. E., L. M. Li, I. Lopes - Cendes, M. M. Guerreiro, C. A. Guerreiro and F. Cendes (2010). "Correlation between quantitative EEG and MRI in idiopathic generalized epilepsy." Human Brain Mapping **31**(9): 1327-1338.

Binder, J. R., J. A. Frost, T. A. Hammeke, P. Bellgowan, S. M. Rao and R. W. Cox (1999). "Conceptual processing during the conscious resting state: a functional MRI study." Journal of Cognitive Neuroscience **11**(1): 80-93.

Brewer, J. A., P. D. Worhunsky, J. R. Gray, Y.-Y. Tang, J. Weber and H. Kober (2011). "Meditation experience is associated with differences in default mode network activity and connectivity." Proceedings of the National Academy of Sciences **108**(50): 20254-20259.

Brill, A. (2013). Meditative prayer in Moshe Cordovero's Kabbalah. Meditation in Judaism, Christianity and Islam: Cultural Histories. H. Eifring, A&C Black.

Buckner, R. L., J. R. Andrews - Hanna and D. L. Schacter (2008). "The brain's default network." Annals of the New York Academy of Sciences **1124**(1): 1-38.

Cahn, B. R. and J. Polich (2006). "Meditation states and traits: EEG, ERP, and neuroimaging studies." Psychological Bulletin **132**(2): 180.

Cardoso, R., E. de Souza, L. Camano and J. R. Leite (2004). "Meditation in health: an operational definition." Brain Research Protocols **14**(1): 58-60.

Corbetta, M., G. Patel and G. L. Shulman (2008). "The reorienting system of the human brain: from environment to theory of mind." Neuron **58**(3): 306-324.

Corbetta, M. and G. L. Shulman (2002). "Control of goal-directed and stimulus-driven attention in the brain." Nature reviews neuroscience **3**(3): 201-215.

Coromaldi, E., M. A. Stadler and C. Basar-Eroglu (2006). "Correlation between EEG-oscillations during deep meditation: A study with a Zen-master." International Journal of Psychophysiology **61**(3): 367-378.

Davidson, R. J. (2010). "Empirical explorations of mindfulness: conceptual and methodological conundrums." Emotion **10**: 8-11.

Davidson, R. J. and D. J. Goleman (1977). "The role of attention in meditation and hypnosis: A psychobiological perspective on transformations of consciousness." International Journal of Clinical and Experimental Hypnosis **25**(4): 291-308.

DeLuca, J. and R. Daly (2004). Mapping the meditative mind: QEEG and LORETA findings. Applied Psychophysiology and Biofeedback. 35th Annual Meeting, PLENUM PUBLISHERS 233 SPRING ST, NEW YORK, NY 10013 USA.29(4),290-291

Desbordes, G., L. T. Negi, T. W. Pace, B. A. Wallace, C. L. Raison and E. L. Schwartz (2012). "Effects of mindful-attention and compassion meditation training on amygdala response to emotional stimuli in an ordinary, non-meditative state." Frontiers in Human Neuroscience **6**.

Dillbeck, M. C. and E. C. Bronson (1981). "Short-term longitudinal effects of the Transcendental Meditation technique on EEG power and coherence." International Journal of Neuroscience **14**(3-4): 147-151.

Dittrich, A. (1985). Ätiologie-unabhängige Strukturen veränderter Wachbewußtseinszustände: Ergebnisse empirischer Untersuchungen über Halluzinogene I. und II. Ordnung, sensorische Deprivation, hypnagoge Zustände, hypnotische Verfahren sowie Reizüberflutung. Stuttgart, Enke.

Dogen (1243/2011). Treasury of the eye of the true dharma, Book 11. Principles of Zazen (Zazen gi).

Dümpelmann, M., T. Ball and A. Schulze‐Bonhage (2012). "sLORETA allows reliable distributed source reconstruction based on subdural strip and grid recordings." Human Brain Mapping **33**(5): 1172-1188.

Dunn, B. R., J. A. Hartigan and W. L. Mikulas (1999). "Concentration and mindfulness meditations: unique forms of consciousness?" Applied Psychophysiology and Biofeedback **24**(3): 147-165.

Eifring, H. (2013). Meditation in Judaism, Christianity and Islam: Cultural Histories [Kindle edition], Bloomsbury Academic.

Etevenon, P., J. Henrotte and G. Verdeaux (1973). "Approche méthodologique des états de conscience modifiés volontairement." Revue d'Electroencéphalographie et de Neurophysiologie Clinique **3**(2): 232-237.

Faber, P. L., D. Lehmann, H. Barendregt, M. Kaelin and L. R. Gianotti (2005). "Increased duration of EEG microstates during meditation." Brain Topography **18**(2): 131.

Faber, P. L., D. Lehmann, L. R. Gianotti, P. Milz, R. D. Pascual-Marqui, M. Held and K. Kochi (2014). "Zazen meditation and no-task resting EEG compared with LORETA intracortical source localization." Cognitive Processing **16**(1): 87-96.

Faber, P. L., D. Lehmann, P. Milz, F. Travis and M. Parim (2014). EEG microstates differ between transcending and mind wandering. ZNZ Symposium, Zurich, abstract booklet p. 54

Faber, P. L., D. Lehmann, S. Tei, T. Tsujiuchi, H. Kumano, R. D. Pascual-Marqui and K. Kochi (2012). "EEG source imaging during two Qigong meditations." Cognitive Processing **13**(3): 255-265.

Fell, J., N. Axmacher and S. Haupt (2010). "From alpha to gamma: Electrophysiological correlates of meditation-related states of consciousness." Medical Hypotheses **75**(2): 218-224.

Feuerstein, G. (2006). Yogic meditation. The experience of meditation: Experts introduce the major traditions. J. Shear, Paragon House**:** 87-117.

Fischer, R. (1971). "A cartography of the ecstatic and meditative states." Science **174**(4012):

897-904.

Fischer, R. (1976). "Transformations of consciousness: A cartography. II: The perception-meditation continuum." Confinia Psychiatrica.

Fox, K. C., P. Zakarauskas, M. Dixon, M. Ellamil, E. Thompson and K. Christoff (2012). "Meditation experience predicts introspective accuracy." PLoS One **7**(9): e45370.

Fox, M. D., A. Z. Snyder, J. L. Vincent, M. Corbetta, D. C. Van Essen and M. E. Raichle (2005). "The human brain is intrinsically organized into dynamic, anticorrelated functional networks." Proceedings of the National Academy of Sciences of the United States of America **102**(27): 9673-9678.

Froeliger, B., E. L. Garland, R. V. Kozink, L. A. Modlin, N.-K. Chen, F. J. McClernon, J. M. Greeson and P. Sobin (2012). "Meditation-state functional connectivity (msFC): strengthening of the dorsal attention network and beyond." Evidence-Based Complementary and Alternative Medicine **2012**.

Fuchs, M., J. Kastner, M. Wagner, S. Hawes and J. S. Ebersole (2002). "A standardized boundary element method volume conductor model." Clinical Neurophysiology **113**(5): 702-712.

Fukunaga, M., S. G. Horovitz, P. van Gelderen, J. A. de Zwart, J. M. Jansma, V. N. Ikonomidou, R. Chu, R. H. Deckers, D. A. Leopold and J. H. Duyn (2006). "Large-amplitude, spatially correlated fluctuations in BOLD fMRI signals during extended rest and early sleep stages." Magnetic Resonance Imaging **24**(8): 979-992.

Gaylord, C., D. Orme-Johnson and F. Travis (1989). "The effects of the transcendental mediation technique and progressive muscle relaxation on EEG coherence, stress reactivity, and mental health in black adults." International Journal of Neuroscience **46**(1-2): 77-86.

Greicius, M. D., G. Srivastava, A. L. Reiss and V. Menon (2004). "Default-mode network activity distinguishes Alzheimer's disease from healthy aging: evidence from functional MRI." Proceedings of the National Academy of Sciences of the United States of America **101**(13): 4637-4642.

Gusnard, D. A., E. Akbudak, G. L. Shulman and M. E. Raichle (2001). "Medial prefrontal cortex and self-referential mental activity: relation to a default mode of brain function." Proceedings of the National Academy of Sciences **98**(7): 4259-4264.

Hämäläinen, M., R. Hari, R. J. Ilmoniemi, J. Knuutila and O. V. Lounasmaa (1993). "Magnetoencephalography—theory, instrumentation, and applications to noninvasive studies of the working human brain." Reviews of modern Physics **65**(2): 413.

Hämäläinen, M. S. and R. J. Ilmoniemi (1984). Interpreting measured magnetic fields of the brain: estimates of current distributions, Helsinki University of Technology, Department of Technical Physics.

Harada-Roshi, S. (2006). Zazen meditation in japanese rinzai zen. The experience of meditation: Experts introduce the major traditions. J. Shear, Paragon House**:** 1-21.

Hasenkamp, W. and L. W. Barsalou (2012). "Effects of meditation experience on functional connectivity of distributed brain networks." Frontiers in Human Neuroscience **6**(38).

Hasenkamp, W., C. D. Wilson-Mendenhall, E. Duncan and L. W. Barsalou (2012). "Mind wandering and attention during focused meditation: a fine-grained temporal analysis of fluctuating cognitive states." Neuroimage **59**(1): 750-760.

Hebert, R. and D. Lehmann (1977). "Theta bursts: an EEG pattern in normal subjects practising the transcendental meditation technique." Electroencephalography and Clinical Neurophysiology **42**(3): 397-405.

Hebert, R., D. Lehmann, G. Tan, F. Travis and A. Arenander (2005). "Enhanced EEG alpha time-domain phase synchrony during Transcendental Meditation: Implications for cortical integration theory." Signal Processing **85**(11): 2213-2232.

Henrotte, J., P. Etevenon and G. Verdeaux (1972). "Les états de conscience modifiés volontairement." La Recherche, Paris **29**(3): 1100-1103.

Hinterberger, T., T. Kamei and H. Walach (2011). "Psychophysiological classification and staging of mental states during meditative practice." Biomedizinische Technik/Biomedical engineering **56**(6): 341-350.

Hinterberger, T., S. Schmidt, T. Kamei and H. Walach (2014). "Decreased electrophysiological activity represents the conscious state of emptiness in meditation." Frontiers in Psychology **5**: 1-14.

Holroyd, J. (2003). "The science of meditation and the state of hypnosis." American Journal of Clinical Hypnosis **46**(2): 109-128.

Imperatori, C., R. Brunetti, B. Farina, A. M. Speranza, A. Losurdo, E. Testani, A. Contardi and G. Della Marca (2014). "Modification of EEG power spectra and EEG connectivity in autobiographical memory: a sLORETA study." Cognitive Processing **15**(3): 351-361.

Irisawa, S., T. Isotani, T. Yagyu, S. Morita, K. Nishida, K. Yamada, M. Yoshimura, G. Okugawa, K. Nobuhara and T. Kinoshita (2006). "Increased omega complexity and decreased microstate duration in nonmedicated schizophrenic patients." Neuropsychobiology **54**(2): 134-139.

Jäncke, L. (2005). Methoden der Bildgebung in der Psychologie und den kognitiven Neurowissenschaften. Stuttgart, Kohlhammer.

Jaseja, H. (2009). "Definition of meditation: Seeking a consensus." Medical hypotheses **72**(4): 483.

Josipovic, Z. (2010). "Duality and nonduality in meditation research." Consciousness and Cognition **19**(4): 1119-1121.

Josipovic, Z. (2013). "Neural correlates of nondual awareness in meditation." Ann. NY Acad. Sci **40**: 1-10.

Josipovic, Z. (2014). "Neural correlates of nondual awareness in meditation." Annals of the New York Academy of Sciences **1307**(1): 9-18.

Josipovic, Z., I. Dinstein, J. Weber and D. Heeger (2012). "Influence of meditation on anti-correlated networks in the brain." Frontiers in Human Neuroscience **5**: 183.

Kasamatsu, A. and T. Hirai (1966). "An electroencephalographic study on the Zen meditation (Zazen)." Psychiatry and Clinical Neurosciences **20**(4): 315-336.

Katayama, H., L. R. Gianotti, T. Isotani, P. L. Faber, K. Sasada, T. Kinoshita and D. Lehmann (2007). "Classes of multichannel EEG microstates in light and deep hypnotic conditions." Brain Topography **20**(1): 7-14.

Keng, S.-L., M. J. Smoski and C. J. Robins (2011). "Effects of mindfulness on psychological health: A review of empirical studies." Clinical Psychology Review **31**(6): 1041-1056.

Khare, K. and S. K. Nigam (2000). "A Study of Electroencephalogram in Mediators." Indian Journal of Physiology and Pharmacology **44**(2): 173-178.

Kiely, W. F. and E. Gellhorn (1972). "Mystical states of consciousness: Neurophysiological and clinical aspects." Journal of Nervous and Mental Disease **154**(6): 399-405.

Koenig, T., K. Kochi and D. Lehmann (1998). "Event-related electric microstates of the brain differ between words with visual and abstract meaning." Electroencephalography and Clinical Neurophysiology **106**(6): 535-546.

Koenig, T., D. Lehmann, M. C. Merlo, K. Kochi, D. Hell and M. Koukkou (1999). "A deviant EEG brain microstate in acute, neuroleptic-naive schizophrenics at rest." European Archives of Psychiatry and Clinical Neuroscience **249**(4): 205-211.

Koenig, T., L. Prichep, D. Lehmann, P. V. Sosa, E. Braeker, H. Kleinlogel, R. Isenhart and E. R. John (2002). "Millisecond by millisecond, year by year: normative EEG microstates and developmental stages." Neuroimage **16**(1): 41-48.

Laxton, A. W., D. F. Tang‐Wai, M. P. McAndrews, D. Zumsteg, R. Wennberg, R. Keren, J. Wherrett, G. Naglie, C. Hamani and G. S. Smith (2010). "A phase I trial of deep brain stimulation of memory circuits in Alzheimer's disease." Annals of Neurology **68**(4): 521-534.

Lee, T. M., M.-K. Leung, W.-K. Hou, J. C. Tang, J. Yin, K.-F. So, C.-F. Lee and C. C. Chan (2012). "Distinct neural activity associated with focused-attention meditation and loving-kindness meditation." PloS One **7**(8): e40054.

Lehmann, D. (1990). Brain electric microstates and cognition: the atoms of thought. Machinery of the Mind. E. Roy John. Boston, Birkhäuser**:** 209-224.

Lehmann, D. (2013). "Consciousness: Microstates of the brain's electric field as atoms of thought and emotion." The Unity of Mind, Brain and World: Current Perspectives on a Science of Consciousness: 191.

Lehmann, D., P. Faber, P. Achermann, D. Jeanmonod, L. R. Gianotti and D. Pizzagalli (2001). "Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self." Psychiatry Research: Neuroimaging

108(2): 111-121.

Lehmann, D., P. L. Faber, S. Galderisi, W. M. Herrmann, T. Kinoshita, M. Koukkou, A. Mucci, R. D. Pascual-Marqui, N. Saito and J. Wackermann (2005). "EEG microstate duration and syntax in acute, medication-naive, first-episode schizophrenia: a multi-center study." Psychiatry Research: Neuroimaging **138**(2): 141-156.

Lehmann, D., P. L. Faber, L. R. Gianotti, K. Kochi and R. D. Pascual-Marqui (2006). "Coherence and phase locking in the scalp EEG and between LORETA model sources, and microstates as putative mechanisms of brain temporo-spatial functional organization." Journal of Physiology-Paris **99**(1): 29-36.

Lehmann, D., P. L. Faber, R. D. Pascual-Marqui, P. Milz, W. M. Herrmann, M. Koukkou, N. Saito, G. Winterer and K. Kochi (2014). "Functionally aberrant electrophysiological cortical connectivities in first episode medication-naive schizophrenics from three psychiatry centers." Frontiers in Human Neuroscience **8**(635).

Lehmann, D., P. L. Faber, S. Tei, R. D. Pascual-Marqui, P. Milz and K. Kochi (2012). "Reduced functional connectivity between cortical sources in five meditation traditions detected with lagged coherence using EEG tomography." Neuroimage **60**(2): 1574-1586.

Lehmann, D., H. Ozaki and I. Pal (1987). "EEG alpha map series: brain micro-states by space-oriented adaptive segmentation." Electroencephalography and Clinical Neurophysiology **67**(3): 271-288.

Lehmann, D., R. D. Pascual-Marqui, W. K. Strik and T. Koenig (2010). "Core networks for visual-concrete and abstract thought content: A brain electric microstate analysis." Neuroimage **49**(1): 1073-1079.

Lehmann, D., W. Strik, B. Henggeler, T. Koenig and M. Koukkou (1998). "Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts." International Journal of Psychophysiology **29**(1): 1-11.

Lehmann, D., J. Wackermann, C. M. Michel and T. Koenig (1993). "Space-oriented EEG segmentation reveals changes in brain electric field maps under the influence of a nootropic drug." Psychiatry Research: Neuroimaging **50**(4): 275-282.

Levine, P. (1976). The coherence spectral array (COSPAR) and its application to the study of spatial ordering in the EEG. Proceedings of the San Diego Biomedical Symposium, Academic Press San Francisco.15(237-247

Liang, S.-Y. and W.-C. Wu (2006). Taoist qigong. The experience of meditation: Experts introduce the major traditions. J. Shear, Paragon House**:** 49-86.

Lifshitz, M., N. K. Campbell and A. Raz (2012). "Varieties of attention in hypnosis and meditation." Consciousness and Cognition **21**(3): 1582-1585.

Lippelt, D. P., B. Hommel and L. S. Colzato (2014). "Focused attention, open monitoring and loving kindness meditation: effects on attention, conflict monitoring, and creativity–A review." Frontiers in Psychology **5**.

Lou, H. C., T. W. Kjaer, L. Friberg, G. Wildschiodtz, S. Holm and M. Nowak (1999). "A 15O-H2O PET study of meditation and the resting state of normal consciousness." Human Brain Mapping **7**(2): 98-105.

Lou, H. C., B. Luber, M. Crupain, J. P. Keenan, M. Nowak, T. W. Kjaer, H. A. Sackeim and S. H. Lisanby (2004). "Parietal cortex and representation of the mental self." Proceedings of the National Academy of Sciences of the United States of America **101**(17): 6827-6832.

Lutz, A., L. L. Greischar, N. B. Rawlings, M. Ricard and R. J. Davidson (2004). "Long-term meditators self-induce high-amplitude gamma synchrony during mental practice." Proceedings of the National Academy of Sciences of the United States of America **101**(46): 16369-16373.

Lutz, A., H. A. Slagter, J. D. Dunne and R. J. Davidson (2008). "Attention regulation and monitoring in meditation." Trends in Cognitive Sciences **12**(4): 163-169.

Malinowski, P. (2013). "Neural mechanisms of attentional control in mindfulness meditation." Frontiers in Neuroscience **7**.

Manna, A., A. Raffone, M. G. Perrucci, D. Nardo, A. Ferretti, A. Tartaro, A. Londei, C. Del Gratta, M. O. Belardinelli and G. L. Romani (2010). "Neural correlates of focused attention and cognitive monitoring in meditation." Brain Research Bulletin **82**(1): 46-56.

Marzetti, L., C. Di Lanzo, F. Zappasodi, F. Chella, A. Raffone and V. Pizzella (2014). "Magnetoencephalographic alpha band connectivity reveals differential default mode network interactions during focused attention and open monitoring meditation." Frontiers in Human Neuroscience **8**.

Mason, M. F., M. I. Norton, J. D. Van Horn, D. M. Wegner, S. T. Grafton and C. N. Macrae (2007). "Wandering minds: the default network and stimulus-independent thought." Science **315**(5810): 393-395.

Maupin, E. W. (1969). On meditation. Altered states of consciousness. C. T. Tart. New York, Wiley.

Mazziotta, J., A. Toga, A. Evans, P. Fox, J. Lancaster, K. Zilles, R. Woods, T. Paus, G. Simpson and B. Pike (2001). "A probabilistic atlas and reference system for the human brain: International Consortium for Brain Mapping (ICBM)." Philosophical Transactions of the Royal Society B: Biological Sciences **356**(1412): 1293-1322.

meditation (2015). "Encyclopædia Britannica."

Mikulas, W. I. (1990). Mindfulness, self-control, and personal growth. Psychotherapy, meditation and health: A cognitive-behavioural perspective. M. G. Kwee. London, East-West**:** 151-164.

Milz, P., P. L. Faber, D. Lehmann, K. Kochi and R. D. Pascual-Marqui (2014). "sLORETA intracortical lagged coherence during breath counting in meditation-naïve participants." Frontiers in Human Neuroscience **8**.

Milz, P., R. Pascual-Marqui and P. L. Faber (in preparation). "Modalities of Thinking are Reflected in EEG Cross-Frequency Functional Independent Brain Networks.".

Nash, J. D. and A. Newberg (2013). "Toward a unifying taxonomy and definition for meditation." Frontiers in Psychology **4**.

Newell, A. (1992). "Précis of unified theories of cognition." Behavioral and Brain Sciences **15**(03): 425-437.

Nolte, G., O. Bai, L. Wheaton, Z. Mari, S. Vorbach and M. Hallett (2004). "Identifying true brain interaction from EEG data using the imaginary part of coherency." Clinical Neurophysiology **115**(10): 2292-2307.

Ott, U. (2001). "The EEG and the depth of meditation." Journal for Meditation and Meditation Research **1**: 55-68.

Ozaki, H. and D. Lehmann (2000). "EEG reconsidered: From neuroelectric signals to human conscious experience." Japanese Journal of Clinical Neurophysiology **28**(1): 15-17.

Pagano, R. R., R. M. Rose, R. M. Stivers and S. Warrenburg (1976). "Sleep during transcendental meditation." Science **191**(4224): 308-310.

Pagnoni, G., M. Cekic and Y. Guo (2008). "“Thinking about not-thinking”: neural correlates of conceptual processing during Zen meditation." PLoS One **3**(9): e3083.

Pascual-Marqui, R. (1993). "The spherical spline Laplacian does not produce artifactually high coherences: comments on two articles by Biggins et al." Electroencephalography and Clinical Neurophysiology **87**(1): 62-64.

Pascual-Marqui, R., M. Esslen, K. Kochi and D. Lehmann (2002). "Functional imaging with low resolution brain electromagnetic tomography (LORETA): review, new comparisons, and new validation." Japanese Journal of Clinical Neurophysiology **30**: 81-94.

Pascual-Marqui, R. D. (1999). "Review of methods for solving the EEG inverse problem." International Journal of Bioelectromagnetism **1**(1): 75-86.

Pascual-Marqui, R. D. (2002). "Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details." Methods Find Exp Clin Pharmacol **24**(Suppl D): 5-12.

Pascual-Marqui, R. D. (2007). "Discrete, 3D distributed, linear imaging methods of electric neuronal activity. Part 1: exact, zero error localization." arXiv preprint arXiv:0710.3341.

Pascual-Marqui, R. D. (2007). "Instantaneous and lagged measurements of linear and nonlinear dependence between groups of multivariate time series: frequency decomposition." arXiv preprint arXiv:0711.1455.

Pascual-Marqui, R. D. and R. J. Biscay-Lirio (2011). "Interaction patterns of brain activity across space, time and frequency. Part I: methods." arXiv preprint arXiv:1103.2852.

Pascual-Marqui, R. D., D. Lehmann, T. Koenig, K. Kochi, M. C. Merlo, D. Hell and M. Koukkou

(1999). "Low resolution brain electromagnetic tomography (LORETA) functional imaging in acute, neuroleptic-naive, first-episode, productive schizophrenia." Psychiatry Research: Neuroimaging **90**(3): 169-179.

Pascual-Marqui, R. D., D. Lehmann, M. Koukkou, K. Kochi, P. Anderer, B. Saletu, H. Tanaka, K. Hirata, E. R. John and L. Prichep (2011). "Assessing interactions in the brain with exact low-resolution electromagnetic tomography." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences **369**(1952): 3768-3784.

Pascual-Marqui, R. D., C. M. Michel and D. Lehmann (1994). "Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain." International Journal of Psychophysiology **18**(1): 49-65.

Pennington, B. (2006). Centering prayer - an ancient christian way of meditation. The experience of meditation: Experts introduce the major traditions. J. Shear, Paragon House.

Piron, H. (2001). "The meditation depth index (MEDI) and the meditation depth questionnaire (MEDEQ)." Journal for Meditation and Meditation Research **1**(1): 69-92.

Plummer, C., M. Wagner, M. Fuchs, S. Vogrin, L. Litewka, S. Farish, C. Bailey, A. Harvey and M. Cook (2010). "Clinical utility of distributed source modelling of interictal scalp EEG in focal epilepsy." Clinical Neurophysiology **121**(10): 1726-1739.

Posner, M. I. and S. E. Petersen (1989). The attention system of the human brain, DTIC Document.

Raffone, A. and N. Srinivasan (2010). "The exploration of meditation in the neuroscience of attention and consciousness." Cognitive Processing **11**(1): 1-7.

Raichle, M. E., A. M. MacLeod, A. Z. Snyder, W. J. Powers, D. A. Gusnard and G. L. Shulman (2001). "A default mode of brain function." Proceedings of the National Academy of Sciences **98**(2): 676-682.

Ruchkin, D. (2005). "EEG coherence." International Journal of Psychophysiology **57**(2): 83-85.

Schlegel, F., D. Lehmann, P. L. Faber, P. Milz and L. R. Gianotti (2012). "EEG microstates during resting represent personality differences." Brain Topography **25**(1): 20-26.

Schwartz, J. M. and B. Clark (2006). Theravada Buddhist meditation. The experience of meditation: Experts introduce the major traditions. J. Shear, Paragon House.

Semmens-Wheeler, R. and Z. Dienes (2012). "The contrasting role of higher order awareness in hypnosis and meditation." The Journal of Mind–Body Regulation **2**(1): 43–57.

Shapiro, S. L. and R. Walsh (2003). "An analysis of recent meditation research and suggestions for future directions." The Humanistic Psychologist **31**(2-3): 86-114.

Shear, J. (2006). The experience of meditation: Experts introduce the major traditions, Paragon House.

Sperduti, M., P. Martinelli and P. Piolino (2012). "A neurocognitive model of meditation based on activation likelihood estimation (ALE) meta-analysis." Consciousness and Cognition **21**(1): 269-276.

Stigsby, B., J. C. Rodenberg and H. B. Moth (1981). "Electroencephalographic findings during mantra mediation (transcendental meditation). A controlled, quantitative study of experienced meditators." Electroencephalography and Clinical Neurophysiology **51**(4): 434-442.

Strelets, V., P. Faber, J. Golikova, V. Novototsky-Vlasov, T. Koenig, L. Gianotti, J. Gruzelier and D. Lehmann (2003). "Chronic schizophrenics with positive symptomatology have shortened EEG microstate durations." Clinical Neurophysiology **114**(11): 2043-2051.

Strik, W., T. Dierks, T. Becker and D. Lehmann (1995). "Larger topographical variance and decreased duration of brain electric microstates in depression." Journal of Neural Transmission/General Section JNT **99**(1-3): 213-222.

Tang, Y.-Y. and M. I. Posner (2013). "Tools of the trade: theory and method in mindfulness neuroscience." Social Cognitive and Affective Neuroscience **8**(1): 118.

Tang, Y.-Y., M. K. Rothbart and M. I. Posner (2012). "Neural correlates of establishing, maintaining, and switching brain states." Trends in Cognitive Sciences **16**(6): 330-337.

Tart, C. T. (1969). States of consciousness. New York, Wiley.

Taylor, V. A., V. Daneault, J. Grant, G. Scavone, E. Breton, S. Roffe-Vidal, J. Courtemanche, A. S. Lavarenne, G. Marrelec and H. Benali (2012). "Impact of meditation training on the default mode network during a restful state." Social Cognitive and Affective Neuroscience: nsr087.

Tebēcis, A. K. (1975). "A controlled study of the EEG during transcendental meditation: comparison with hypnosis." Psychiatry and Clinical Neurosciences **29**(4): 305-313.

Tei, S., P. L. Faber, D. Lehmann, T. Tsujiuchi, H. Kumano, R. D. Pascual-Marqui, L. R. Gianotti and K. Kochi (2009). "Meditators and non-meditators: EEG source imaging during resting." Brain Topography **22**(3): 158-165.

Thomas, J. W. and M. Cohen (2014). "A methodological review of meditation research." Frontiers in Psychiatry **5**.

Tomasino, B., A. Chiesa and F. Fabbro (2014). "Disentangling the neural mechanisms involved in Hinduism-and Buddhism-related meditations." Brain and Cognition **90**: 32-40.

Tomasino, B., S. Fregona, M. Skrap and F. Fabbro (2013). "Meditation-related activations are modulated by the practices needed to obtain it and by the expertise: an ALE meta-analysis study." Frontiers in Human Neuroscience **6**.

Tooley, G. A., S. M. Armstrong, T. R. Norman and A. Sali (2000). "Acute increases in night-time plasma melatonin levels following a period of meditation." Biological Psychology **53**(1): 69-78.

Travis, F. (2001). "Autonomic and EEG patterns distinguish transcending from other experiences during Transcendental Meditation practice." International Journal of Psychophysiology **42**(1): 1-9.

Travis, F. and A. Arenander (2006). "Cross-sectional and longitudinal study of effects of transcendental meditation practice on interhemispheric frontal asymmetry and frontal coherence." International Journal of Neuroscience **116**(12): 1519-1538.

Travis, F. and J. Shear (2010). "Focused attention, open monitoring and automatic self-transcending: categories to organize meditations from Vedic, Buddhist and Chinese traditions." Consciousness and Cognition **19**(4): 1110-1118.

Travis, F., J. Tecce, A. Arenander and R. K. Wallace (2002). "Patterns of EEG coherence, power, and contingent negative variation characterize the integration of transcendental and waking states." Biological psychology **61**(3): 293-319.

Travis, F. and R. K. Wallace (1999). "Autonomic and EEG patterns during eyes-closed rest and transcendental meditation (TM) practice: the basis for a neural model of TM practice." Consciousness and Cognition **8**(3): 302-318.

Travis, F. T. and D. W. Orme-Johnson (1989). "Field model of consciousness: EEG coherence changes as indicators of field effects." International Journal of Neuroscience **49**(3-4): 203-211.

Tsai, J.-F., S.-H. Jou, W. Cho and C.-M. Lin (2013). "Electroencephalography when meditation advances: a case-based time-series analysis." Cognitive Processing **14**(4): 371-376.

Vaitl, D., N. Birbaumer, J. Gruzelier, G. A. Jamieson, B. Kotchoubey, A. Kübler, U. Strehl, D. Lehmann, W. H. Miltner and T. Weiss (2013). "Psychobiology of altered states of consciousness." Psychology of Consciousness: Theory, Research, and Practice **1**: 2-47.

Walach, H. (2014). Towards an Epistemology of Inner Experience. Meditation–Neuroscientific Approaches and Philosophical Implications, Springer**:** 7-22.

West, M. A. (1980). "Meditation and the EEG." Psychological Medicine **10**(02): 369-375.

Xu, J., A. Vik, I. R. Groote, J. Lagopoulos, A. Holen, Ø. Ellingsen, A. K. Håberg and S. Davanger (2014). "Nondirective meditation activates default mode network and areas associated with memory retrieval and emotional processing." Frontiers in Human Neuroscience **8**.

Xue, S., Y.-Y. Tang and M. I. Posner (2011). "Short-term meditation increases network efficiency of the anterior cingulate cortex." Neuroreport **22**(12): 570-574.

Yoshimura, M., T. Koenig, S. Irisawa, T. Isotani, K. Yamada, M. Kikuchi, G. Okugawa, T. Yagyu, T. Kinoshita and W. Strik (2007). "A pharmaco-EEG study on antipsychotic drugs in healthy volunteers." Psychopharmacology **191**(4): 995-1004.

Younger, J., W. Adriance and R. J. Berger (1975). "Sleep during transcendental meditation." Perceptual and Motor Skills **40**(3): 953-954.

Yu, X., M. Fumoto, Y. Nakatani, T. Sekiyama, H. Kikuchi, Y. Seki, I. Sato-Suzuki and H. Arita

(2011). "Activation of the anterior prefrontal cortex and serotonergic system is associated with improvements in mood and EEG changes induced by Zen meditation practice in novices." International Journal of Psychophysiology **80**(2): 103-111.

Acknowledgements

This thesis was realized under the direction of Prof. Dr. rer. nat. Lutz Jäncke. His enthusiasm and positive and supportive attitude convinced me not only to start but also to finish my work on this doctoral thesis.

Prof. Dr. med. Dr. med. h.c. Dietrich Lehmann has been my mentor for many years and in more ways than I can possibly think of. It was a great shock for me, when he passed away on June 16th, 2014. It is very sad that he could not see the completion of this thesis.

I definitely wish to thank my beautiful and clever wife Lisa, who relentlessly encouraged me to keep working on my doctoral thesis. My wife and our two children Nikki and Eric are a source of endless wonder and joy and are all three to no small amount responsible for me getting through with this work.

I am especially grateful to Dr. med. Kieko Kochi, the president of the the KEY Foundation and the director of the KEY Institute for Brain-Mind Research, Zurich. Without her support, this thesis would not have been possible.

Finally, I want to express my gratitude to the Bial Foundation, S. Mamede do Coronado, Portugal. Some of the studies presented in this thesis were supported in part by Grant Nr. 44/06 from the Bial Foundation.

Curriculum Vitae

Pascal Luc Eloi FABER

Born January 5th, 1965 in Luxemburg, Luxemburg

Citizen of Hendschiken/AG, Switzerland

Studies

1988 - 1995	Psychology, Faculty of Arts I, University of Zurich/ZH, Switzerland
	1st minor: Psychopathology (Prof. Chr. Scharfetter)
	2nd minor: Social and preventive medicine (Prof. F. Gutzwiler)
1985 - 1988	Computer science, ETH Zürich
1977 - 1985	High school at Lycée Michel Rodange, Luxemburg
1971 - 1977	Primary school, Mamer, Luxemburg

Examination and Degree

1995	Licentiate in Psychology at the Faculty of Arts I, University of Zurich

Present Position

Institute Coordinator,
The KEY Institute for Brain-Mind Research, Department of Psychiatry, Psychotherapy and Psychosomatics, University Hospital of Psychiatry, Zurich.

Past Positions

1999 – now	Member and Institute Coordinator (since 2012), The KEY Institute for Brain-Mind Research, Department of Psychiatry, Psychotherapy and Psychosomatics, University Hospital of Psychiatry, Zurich.
1998 (Jan - July)	Research Assistant at the 'Schweizerische Graphologische Gesellschaft', Zurich, Switzerland
1996 – 1997	Analyst / Programmer at CS Columna, then group leader in IT/logistics at the legal follow-up company Winterthur-Columna, Winterthur, Switzerland
1995 – 1996	IT-Specialist / system administrator at UPT-Consulting, Herrliberg, Switzerland
1993 – 1994	Sleep Laboratory Assistent at the 'Schlaflabor Fluntern', Zurich, Switzerland

Publications

Articles in Peer Reviewed Journals

2015-2 Milz, P., **Faber, P.L.**, Lehmann, D., Koenig, T., Kochi, K. & Pascual-Marqui, R.D. (in press). The functional significance of EEG microstates - associations with modalities of thinking. *NeuroImage*.

2015-1 **Faber, P.L.**, Milz, P., Lehmann, D. (2015). EEG of two persons during their roles as spiritual trance healer and as client – a pilot study. *Human Cognitive Neurophysiology*, 8(1): 23-29.

2014-6 Pascual-Marqui, R.D., Lehmann, D., **Faber, P.L.**, Milz, P., Kochi K., Yoshimura, M., Nishida, K., Isotani, T. & Kinoshita, T. (2014). The resting microstate networks (RMN): cortical distributions, dynamics, and frequency specific information flow. *arXiv*:1411.1949 [q-bio.NC]

2014-5 **Faber, P.L.**, Lehmann, D., Gianotti, L.R., Milz, P., Pascual-Marqui, R.D., Held, M. & Kochi, K. (2014). Zazen meditation and no-task resting EEG compared with LORETA intracortical source localization. *Cognitive Processing*, 16(1), 87-96. DOI: 10.1007/s10339-014-0637-x

2014-4 Lehmann, D., **Faber, P.L.**, Pascual-Marqui, R.D., Milz, P., Herrmann, W.M., Koukkou, M., Saito, N., Winterer, G. & Kochi, K. (2014). Functionally aberrant electrophysiological cortical connectivities in first episode medication-naive schizophrenics from three psychiatry centers. *Frontiers in human neuroscience*, 8. DOI: 10.3389/fnhum.2014.00635

2014-3 Painold, A., **Faber, P.L.**, Milz, P., Reininghaus, E.Z., Holl, A.K., Letmaier, M., Pascual-Marqui, R.D., Reininghaus, B., Kapfhammer, H.-P. & Lehmann, D. (2014). Brain Electrical Source Imaging in Manic and Depressive Episodes of Bipolar Disorder. *Bipolar Disorders*, 16(7), 690-702. DOI: 10.1111/bdi.12198.

2014-2 Milz, P., **Faber, P.L.**, Lehmann, D., Kochi, K. & Pascual-Marqui, R.D. (2014). sLORETA intracortical lagged coherence during breath counting in meditation-naïve participants. *Frontiers in Human Neuroscience*, 8:303. DOI: 10.3389/fnhum.2014.00303. eCollection 2014.

2014-1 Andreou, C., **Faber, P.L.**, Leicht, G., Schoettle, D., Polomac, N., Hanganu-Opatz, I.L., Lehmann, D. & Mulert, C. (2014). Resting-state connectivity in the prodromal phase of schizophrenia: insights from EEG microstates. *Schizophrenia Research*, 152(2-3):513-520.

2012-4 **Faber, P.L.**, Lehmann, D., Tei, S., Tsujiuchi, T., Kumano, H., Pascual-Marqui, R.D. & Kochi, K. (2012). EEG source imaging during two Qigong meditations. *Cognitive Processing*, 13(3):255-65. DOI: 10.1007/s10339-012-0441-4.

2012-3 Lehmann, D., **Faber, P.L.**, Tei, S., Pascual-Marqui, R.D., Milz, P. & Kochi, K. (2012). Reduced functional connectivity between cortical sources in five meditation traditions detected with lagged coherence using EEG tomography. *NeuroImage*, 60(2), 1574-1586.

2012-2 Cardeña, E., Lehmann, D., **Faber, P.L.**, Jönsson, P., Milz, P., Pascual-Marqui, R.D. & Kochi, K. (2012). EEG sLORETA Functional Imaging During Hypnotic Arm Levitation and Voluntary Arm Lifting. *The International Journal of Clinical and Experimental Hypnosis*, 60(1), 31-53.

2012-1 Schlegel, F., Lehmann, D., **Faber, P.L.**, Milz, P. & Gianotti, L.R.R. (2012). EEG microstates during resting represent personality differences. *Brain Topography*, 25(1), 20-6. DOI: 10.1007/s10548-011-0189-7.

2009-2 Gianotti, L.R., Knoch, D., **Faber, P.L.**, Lehmann, D., Pascual-Marqui, R.D., Diezi, C., Schoch, C., Eisenegger, C. & Fehr, E. (2009). Tonic activity level in the right prefrontal cortex predicts individuals' risk taking. *Psychological science*, 20(1): 33-8.

2009-1 Tei, S., **Faber, P.L.**, Lehmann, D., Tsujiuchi, T., Kumano, H., Pascual-Marqui, R.D., Gianotti, L.R. & Kochi, K. (2009). Meditators and non-meditators: EEG source imaging during resting. *Brain Topography*, 22(3): 158-65.

2008-2 Gianotti, L.R., **Faber, P.L.**, Schuler, M., Pascual-Marqui, R.D., Kochi, K. & Lehmann, D. (2008).

First valence, then arousal: the temporal dynamics of brain electric activity evoked by emotional stimuli. *Brain Topography*, 20(3):143-56.

2008-1 Gianotti, L.R., Künig, G., **Faber, P.L.**, Lehmann, D., Pascual-Marqui, R.D., Kochi, K. & Schreiter-Gasser U. (2008). Rivastigmine effects on EEG spectra and three-dimensional LORETA functional imaging in Alzheimer's disease. *Psychopharmacology*, 198(3):323-32.

2007-2 Katayama, H., Gianotti, L.R., Isotani, T., **Faber, P.L.**, Sasada, K., Kinoshita, T. & Lehmann, D. (2007). Classes of multichannel EEG microstates in light and deep hypnotic conditions. *Brain Topography*, 20(1):7-14.

2007-1 Gianotti, L.R.R., Künig, G., Lehmann, D., **Faber, P.L.**, Pascual-Marqui, R.D., Kochi, K. & Schreiter-Gasser, U. (2007). Correlation between disease severity and brain electric LORETA tomography in Alzheimer's disease. *Clinical Neurophysiology*, 118: 186-196.

2006-2 Gianotti, L.R.R., **Faber, P.L.**, Pascual-Marqui, R.D., Kochi, K. & Lehmann, D. (2006). Processing of positive versus negative emotional words is incorporated in anterior versus posterior brain areas: an ERP microstate LORETA study. *Chaos and Complexity Letters*, 2: 189-211.

2006-1 Lehmann, D., **Faber, P.L.**, Gianotti, L.R.R., Kochi, K. & Pascual-Marqui, R.D. (2006). Coherence and phase locking in the scalp EEG and between LORETA model sources, and microstates as putative mechanisms of brain temporo-spatial functional organization. *Journal of Physiology – Paris*, 99: 29-36.

2005-1 Lehmann, D., **Faber, P.L.**, Galderisi, S., Herrmann, W. M., Kinoshita, T., Koukkou, M., Mucci, A., Pascual-Marqui, R.D., Saito, N., Wackermann, J., Winterer, G. & Koenig, T. (2005). EEG microstate duration and syntax in acute, medication-naïve, first-episode schizophrenia: a multi-center study. *Psychiatry Research: Neuroimaging*, 138: 141-156.

2004-1 Tsuno, N., Shigeta, M., Hyoki, K., **Faber, P.L.** & Lehmann, D. (2004). Fluctuations of source locations of EEG activity during transition from alertness to sleep in Alzheimer's disease and vascular dementia. *Neuropsychobiology*, 50(3): 267-72.

2003-1 Strelets V., **Faber P.L.**, Golikova J., Novototsky-Vlasov V., Koenig T., Gianotti L.R.R., Gruzelier J.H. & Lehmann, D. (2003). Chronic schizophrenics with positive symptomatology have shortened EEG microstate durations. *Clinical Neurophysiology*, 114(11): 2043-51.

2002-1 Tsuno, N., Shigeta, M., Hyoki, K., Kinoshita, T., Ushijima, S., **Faber, P.L**. & Lehmann, D. (2002). Spatial organization of EEG activity from alertness to sleep stage 2 in old and younger subjects. J. *Sleep Research*, 11: 43-51.

2001-2 Lehmann, D., **Faber, P.L.**, Gianotti, L.R.R., Isotani, T. & Wohlgemuth, P. (2001). Source locations of EEG frequency bands during hypnotic arm levitation: a pilot study. *Contemporary Hypnosis*, 18(3): 120-127.

2001-1 Lehmann, D., **Faber, P.L.**, Achermann, P., Jeanmonod, D., Gianotti, L.R.R. & Pizzagalli, D. (2001). Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. *Psychiatry Research Neuroimaging*, 108: 111-121.

Articles in Books

2002-1 Gianotti, L.R.R, **Faber, P.L.** & Lehmann, D. (2002). EEG source locations after guessed random events in believers and skeptics of paranormal phenomena. In: K. Hirata, Y. Koga, K. Nagata, K. Yamazaki (eds.): Recent Advances in Human Brain Mapping [International Congress Series 1232C]. Amsterdam: Elsevier [0-444-50755-8], pp. 439-441.

2000-1 **Faber, P.L.**, Lehmann, D. Achermann, P., Jeanmonod, D. & Gianotti, L.R.R. (2000). Brain sources of EEG gamma frequency differ between various meditation-induced, altered states of consciousness. Proceedings of Presented Papers: The Parapsychological Association 43rd Annual Convention. 390-391.

Abstracts in Peer Reviewed Journals (a selection)

2012-1 Painold, A., Milz, P., **Faber, P.L.**, Anderer, P., Kapfhammer, H-P., Kochi, K. & Lehmann, D. (2012). Reduced intracortical functional connectivity in Huntington's disease. *European Psychiatry*, 27, Supplement 1: 1.

2011-2 **Faber, P.L.**, Lehmann, D., Milz, P., Tei S. & Kochi, K. (2011). Dimensionality of multichannel EEG (Omega Complexity) during meditation in five traditions. *European Psychiatry,* 26, Supplement 1: 944.

2011-1 Milz, P., Theodoropoulou, A., Tei, S., **Faber, P.L.**, Kochi, K. & Lehmann, D. (2011). Common EEG spectral power characteristics during meditation in five meditation traditions. *European Psychiatry*, 26, Supplement 1: 944.

2010-5 **Faber, P.L.**, Milz, P., Schlegel, F.& Lehmann, D. (2010). Brain LORETA functional imaging, EEG spectral power, and self-rated headache pain. *Swiss Archives of Neurology and Psychiatry*, (SANP) 161[4]: 3S.

2010-4 **Faber, P.L.**, Tei, S., Chen, C., Hsiao, P. & Lehmann, D. (2010). EEG power spectra, LORETA areas and self-rated headache pain. *Human Cognitive Neurophysiology*, 2010, 3[1]: 48-49.

2010-3 **Faber, P.L.**, Tei, S., Chen, C., Hsiao, P. & Lehmann, D. (2010). Brain LORETA functional imaging, EEG spectral power, and self-rated headache pain. *Swiss Arch Neurol Psychiat*., (SANP) 161[4]: 3S.

2010-2 Milz, P., **Faber, P.L.**, Pascual-Marqui, R.D. & Lehmann, D. (2010). Intracerebral functional (LORETA) connectivity during attention to bodily and mental processes and resting. *European Psychiatry*, 25, Suppl. 1: 775.

2010-1 Milz, P., **Faber, P.L.**, Pascual-Marqui, R.D. & Lehmann, D. (2010). EEG-LORETA lagged coherence during resting, attention to calculation and attention to breathing. *Human Cognitive Neurophysiology*, 3[1]: 39-40.

2009-6 Lehmann, D., **Faber, P.L.**, Kochi, K., Koenig, T. & Koukkou, M. (2009). EEG Global Dimensionality and language processing in juveniles and adults. *Neuropsychobiology*, 59(2): 65.

2009-5 Tei, S., **Faber, P.L.**, Lehmann, D., Tsujiuchi, T., Pascual-Marqui, R.D. & Kumano, H. (2009). EEG frequency-band LORETA distinguishes meditation from resting in Qigong meditators. *Neuropsychobiology*, 59(2): 65-66.

2009-4 Lehmann, D., Tei, S., **Faber, P.L.**, Kumano, H., Gianotti, L.R.R. & Kochi, K. (2009). EEG in Tibetan Buddhist meditators during rest and meditation, and effects of meditation experience. *Human Cognitive Neurophysiology*, 2 (1): 12-13.

2009-3 **Faber, P.L.**, Tei, S., Lehmann, D., Gianotti, L.R.R., Tsujiuchi, T., Kumano, H. & Kochi, K. (2009). Active intracerebral areas (EEG LORETA) in non-meditators and experienced meditators differ during resting. *Human Cognitive Neurophysiology*, 2 (1): 9-10.

2009-2 **Faber, P.L.**, Tei, S., Pascual-Marqui, R.D., Gianotti, L.R.R., Kumano, H., Kochi, K. & Lehmann, D. (2009). Scalp EEG connectivity and intracerebral electrical connectivity (sLORETA lagged coherence) during resting and five meditation traditions. *Human Cognitive Neurophysiology*, 2 (1): 8-9.

2009-1 Dahinden, F.M., Gianotti, L.R.R., Künig, G., Pascual-Marqui, R.D., **Faber, P.L.**, Lehmann, D., Kochi, K. & Schreiter-Gasser, U. (2009). Resting EEG-based intracortical functional connectivity in Alzheimer's disease and frontotemporal degeneration. *Human Cognitive Neurophysiology*, 2 (1): 8.

2008-5 **Faber, P.L.**, Steiner, M.E., Lehmann, D., Pascual-Marqui, R.D., Jäncke, L., Esslen, M. & Gianotti, L.R.R. (2008). Deactivation of the medial prefrontal cortex in experienced Zen meditators. *Brain Topography*, 20: 172.

2008-4 Gianotti, L.R., **Faber, P.L.**, Schuler, M., Pascual-Marqui, R.D., Kochi, K. & Lehmann, D. (2008). First valence, then arousal: the temporal dynamics of brain electric activity evoked by emotional stimuli. *Brain Topography*, 20(3): 143-56.

2008-3 **Faber, P.L.**, Tei, S., Pascual-Marqui, R.D., Gianotti, L. R. R., Kumano, H., Kochi, K. & Lehmann, D. (2008). Scalp EEG connectivity and intracerebral electrical connectivity (sLORETA-lagged coherence) during resting and meditation. *Swiss Archives of Neurology and Psychiatry*, 159(7): 466. (SGBP, Basel).

2008-2 Dahinden, F.M., Gianotti, L. R. R., Künig, G., Pascual-Marqui, R.D., **Faber, P.L.**, Lehmann, D., Kochi, K. & Schreiter-Gasser, U. (2008). Resting EEG-based intracortical functional connectivity in Alzheimer's disease and frontotemporal degeneration. *Swiss Archives of Neurology and Psychiatry*, 159(7): 465. (SGBP, Basel).

2008-1 Lehmann, D., Pascual-Marqui, R. D., Waltinger, T. P., **Faber, P. L.**, Koenig, T., Gianotti, L. R. R., Kochi, K. & Strik, W. K. (2008). Neuroleptic medication in schizophrenic patients increases intracerebral EEG connectivity (sLORETA-based lagged coherence). *Swiss Archives of Neurology and Psychiatry*, 159(7): 464. (SGBP, Basel).

2007-1 Eto, Y., **Faber, P.L.**, Gianotti, L., Kochi, K., Kumano, H., Lehmann, D., Tei, S., Tsujiuchi, T., Yamamoto, R. (2007). Headache patients' EEG changed by breath counting exercise. 13th Congress of the International Headache Society. Stockholm, Sweden, Jun 28-Jul 01, 2007. *Cephalgia*, 27[6]: 722-722.

2006-5 Tei, S., **Faber, P.L.**, Lehmann, D., Shibata, I., Ohyama, G., Tsujiuchi, H., Kumano, T., Akabayashi, A., Kochi, K. & Gianotti, L.R.R. (2006). Magnitude and location of EEG spectral power in experienced QiGong meditators during resting and three meditations. *Journal of Psychosomatic Research*, 61(3): 420.

2006-4 Tei, S., **Faber, P.L.**, Lehmann, D., Tsujiuchi, H., Akabayashi, A., Gianotti, L.R.R., Kochi, K. & T. Kumano. (2006). Brain functional plasticity of EEG theta location due to meditation experience. *Journal of the International Neuropsychological Society*, 12 (Suppl 2): 83.

2006-3 Tei, S., **Faber, P.L.**, Lehmann, D., Tsujiuchi, T. Kumano, H., Akabayashi, A., Gianotti, L.R.R. & Kochi, K. (2006). Experience influences the EEG theta localizations in QiGong meditation. *International Journal of Psychophysiology*, 61: 367-378.

2006-2 **Faber, P.L.**, Gianotti, L.R.R., Schuler, M. & Lehmann, D. (2006). Different multichannel ERP responses to positive and negative emoticons (smileys). *Brain Topography*, 18(3): 228.

2006-1 Gianotti, L.R.R., **Faber, P.L.**, Schuler, M., Kochi, K. & Lehmann, D. (2006). Representation of valence and arousal in certain ERP microstates during perception of emotional pictures. *Brain Topography*, 18(3): 225.

2005-7 Katayama, H., Isotani, T., Gianotti, L.R.R., **Faber, P.L.**, Sasada, K., Kinoshita, T. & Lehmann, D. (2005). EEG microstates during light and deep hypnosis viewed in the framework of altered states of consciousness. *Brain Topography*, 18: 8.

2005-6 **Faber, P.L.**, Lehmann, D., Barendregt, H., Kaelin, M. & Gianotti, L.R.R. (2005). Increased duration of EEG microstates during meditation. *Brain Topography*, 18: 7.

2005-5 **Faber, P.L.**, Gianotti, L.R.R., Schuler, M.P. & Lehmann, D. (2005). Preferential processing of negative over positive emoticons (smileys) in a multichannel ERP study. *Brain Topography*, 18(2): 125.

2005-4 Lehmann, D., **Faber, P.L.**, Gianotti, L.R.R., Kochi, K. & Pascual-Marqui, R.D. (2005). Brain mechanisms of temporo-spatial organization: Microstates, and coherence and phase locking (in scalp EEG and intracerebral LORETA model sources). *Brain Topography*, 17: 177-178.

2005-3 Gianotti, L.R.R., **Faber, P.L.**, Pascual-Marqui, R.D., Katayama, H., Kochi, K. & Lehmann, D.

(2005). Emotional valence-sensitive, early brain electric ERP microstates during word processing, and their LORETA functional tomography. *Brain Topography*, 17: 186.

2005-2 Katayama, H., Isotani, T., Gianotti, L.R.R., **Faber, P.L.**, Sasada, K., Kinoshita, T. & Lehmann, D. (2005). Multichannel EEG microstate analysis distinguishes light and deep hypnotic states. *Brain Topography*, 17: 182.

2005-1 **Faber, P.L.**, Lehmann , D., Gianotti, L.R.R., Kaelin, M., Kochi, K. & Pascual-Marqui, R.D.(2005). Scalp EEG coherence and Intracortical LORETA-based coherence during meditational states. *Brain Topography*, 17: 181.

2004-6 Gianotti, L.R.R., Künig, G., Lehmann, D., **Faber, P.L.**, Pascual-Marqui, R.D., Kochi, K. & Schreiter Gasser, U. (2004) Rivastigmine medication in Alzheimer patients affects EEG frequency-domain source localizations and LORETA tomography. *European Psychiatry*, 19(S1): 153s.

2004_5 Tsuno, N., Shigeta, M., Hyoki, K., **Faber, P.L.** & Lehmann, D. (2004). Fluctuations of source locations of EEG activity during sleep onset in Alzheimer and vascular dementia. *European Psychiatry*, 19(S1): 153s.

2004-4 Gianotti, L.R.R., **Faber, P.L.**, Pascual-Marqui, R.D., Katayama, H., Kochi, K. & Lehmann, D. (2004). Reading of emotional words affects very early brain electric ERP microstates (<100 msec) and their functional tomography. *European Psychiatry*, 19(S1): 150s-151s.

2004_3 Lehmann, D., **Faber, P.L.**, Galderisi, S., Kinoshita, T., Koukkou, M., Mucci, A., Saito, N., Wackermann, J., Winterer, G. & Koenig, T. (2004). Syntax of EEG microstates in first episode, acute, medication-naive schizophrenics. *Schizophrenia Research*, 67(S1): 130-131.

2004-2 Gianotti, L.R.R., **Faber, P.L.**, Pascual-Marqui, R.D., Katayama, H., Kochi, K. & Lehmann, D. (2004). Processing of positive versus negative emotion is incorporated in anterior versus posterior brain areas: an ERP microstate LORETA study. *European Archives of Psychiatry and Clinical Neuroscience*, 254(1): I/17.

2004-1 Gianotti, L.R.R., **Faber, P.L.**, Pascual-Marqui, R.D., Katayama, H., Kochi, K. & Lehmann, D. (2204). Emotional valence-sensitive, early brain electric ERP microstates during word processing, and their LORETA functional tomography. *International Journal of Psychophysiology*, 54: 43.

2003-4 Lehmann, D., **Faber, P.L.**, Galderisi, S., Gianotti, L.R.R., Hermann, W.M., Kinoshita, T., Koukkou, M., Mucci, A., Saito, N., Wackermann, J., Winterer, G. & Koenig, T. (2003). Geänderte Verkettung der Spontan-EEG-Mikrozustände in akuter, unbehandelter Schizophrenie. *Klinische Neurophysiologie*, 3: A.24.

2003-3 Gianotti, L.R.R., **Faber, P.L.**, Pascual-Marqui, R.D., Kochi, K. & Lehmann, D. (2003). Lesen emotionaler Wörter und E RP-Mikrozust ände: Drei Informations-Verarbeitungsschritte der ERP-Kartenserien unterscheiden positive von negativen Emotionen. *Klinische Neurophysiologie*, 3: A.12 (2003).

2003-2 Gianotti, L.R.R., Künig, G., **Faber, P.L.**, Pascual-Marqui, R.D., Kochi, K., Lehmann, D. & Schreiter Gasser, U. (2003). Effects of Rivastigmine medication in Alzheimer patients using frequency-domain dipole modeling and LORETA. *Brain Topography*, 16: 126.

2003-1 Gianotti, L.R.R., **Faber P.L.**, Pascual-Marqui R.D., Kochi K. & Lehmann D. (2003). Very early affect-modulated brain electric microstates (~100 msec) during word processing, and their functional tomography. *NeuroImage*, Vol. 19, No.2.

2002-7 **Faber, P.L.**, Lehmann, D., Pütz, P., Gianotti, L.R.R., Strauch, I. & Wackermann, J. (2002). EEG source locations during ganzfeld, sleep onset and waking. *Brain Topography*, 14: 349-350.

2002-6 **Faber, P.L.**, Wohlgemut, P., Gianotti, L.R.R. & Lehmann, D. (2002). EEG source locations during voluntary and hypnotic arm levitation in a pilot study. *Psychiatry Research: Neuroimaging*, 114: 175/76.

2002-5 Gianotti, L.R.R., **Faber, P.L.** & Lehmann, D. (2002). EEG source locations in believers and skeptics of paranormal phenomena after guessed random events. Brain Topography 14(3): 257.

2002-4 Gianotti, L.R.R., **Faber, P.L.** & Lehmann, D. (2002). Event-related brain microstates when reading emotionally positive, negative and neutral words. *Brain Topography*, 14: 350.

2002-3 Gianotti, L.R.R., Lehmann, D., **Faber, P.L.** & Schreiter Gasser, U. (2002). Resting EEG microstates in Alzheimer patients before and after rivastigmine medication. *Psychiatry Research: Neuroimaging*, 114: 178/79.

2002-2 Strelets, V., Golikova, J., Novototsky-Vlasov, V., Gianotti, L.R.R., **Faber, P.L.** & Lehmann, D. (2002). Shortened EEG microstate duration in schizophrenics with positive symptomatology. *Psychiatry Research: Neuroimaging*, 114: 193.

2002-1 Tsuno, N., Shigeta, M., Hyoki, K., Kinoshita, T., Ushijima, S., **Faber, P.L.** & Lehmann, D. (2002). EEG frequency band sources from alertness to sleep stage2 in old and younger subjects. *Brain Topography*, 14: 349-351.

2001-2 Gianotti, L.R.R., **Faber, P.L.** & Lehmann, D. (2001). Brain electric activity in believers and critics of paranormal phenomena after correctly or incorrectly guessed random events. *Brain Topography*, 13(4): 315.

2001-1 **Faber, P.L.**, Gianotti, L.R.R., Achermann, P., Jeanmonod, D. & Lehmann, D. (2001). Brain sources of EEG gamma frequency distinguish different meditation-induced, altered states of consciousness. Brain Topography, 13(4): 315.

2000-4 Lehmann, D., Pizzagalli, D., Gianotti, L., **Faber, P.L.**, Wackermann, J., Tanaka, H., Strauch, I. & Brugger, P. (2000). Brain electric states before correctly and before incorrectly guessed random events. *Brain Topography*, 12: 299.

2000-3 Lehmann, D., Pizzagalli, D., Gianotti, L., **Faber, P.L.**, Wackermann, J., Tanaka, H., Strauch, I. & Brugger, P. (2000). Brain electric correlates of precognition. *International Journal of Psychophysiology*, 35: 42.

2000-2 **Faber, P.L.**, Gianotti, L., Achermann, P. & Lehmann, D. (2000). Different meditation-induced, altered states of consciousness show different EEG source locations. *Archives Suisses de Neurologie et de Psychiatrie (Schweizer Archiv fuer Neurologie und Psychiatrie)*, 6: 151.

2000-1 Gianotti, L., Pizzagalli, D., **Faber, P.L.**, Brugger, P. & Lehmann, D. (2000). Brain electric tomography (LORETA) in healthy subjects who believe or disbelieve in paranormal phenomena. *Archives Suisses de Neurologie et de Psychiatrie (Schweizer Archiv fuer Neurologie und Psychiatrie)*, 6: 151.